THE GEOLOGY AND PETROLOGY OF THE ENGARUKA - OLDONYO L'ENGAI - LAKE NATRON AREA OF NORTHERN TANGANYIKA TERRITORY

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The Geology and Petrology of the Engaruka - Oldonyo L'Engai - Lake Natron area of Northern Tanganyika Territory

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SUMMARY

This region lies in the northern part of the Tanganyika Gregory Rift Valley. Amongst certain aspects which are considered in less detail are the questions of tectonics and age, the rocks of the basement complex, and the geology of Lake Natron.

The main work consists of the systematic petrography of a group of Older Extrusives, andesitic and basaltic rocks, and of a series of Younger Extrusives, soda-rich alkaline rocks, including the carbonatites of the volcano, Kerimasi.

The former occurred after a period of rift faulting; they are associated with larger volcanoes, and cover greater areas than the probable Upper Pleistocene Younger Extrusives.

Utilizing 12 new chemical analyses of rocks, 2 partial analyses, and incorporating all additional known rock analyses, a regional magmatic trend is outlined, with a parent magma of basic-andesitic composition, believed to have been derived from an olivine-basalt magma. This parent magma exhibits differentiation by fractional crystallisation together with alteration through contamination with the basement rocks.

To the east, on the volcanoes of Ketumbaine and Gelai, the magmatic trend is essentially, basic-andesite, andesite, Mawenzi-trachyandesite, phonolite, phonolitic-trachyte, trachyte. Nepheline-melabasalt, nepheline-andesite, mugearite, and nephelinitic-phonolites were also noted. Similar rocks were mapped on the rift wall to the west.

After further rift-faulting, the nephelinitic-phonolite magma was further contaminated with the basement rocks, as shown by the fenites and tveitåsites noted on the active volcano of Oldonyo L'Engai. Moreover, the nephelinitic-phonolite magma was desilicated by the assimilation of basement dolomitic limestone, and carbonatite was formed. Subsequently the source of the limestone having become exhausted, the parent

magma returned to near its pre-desilication composition.

A detailed geological map has been constructed, and photomicrographs have been made of slides of most of the rock types.

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General Introduction, Topographical Notes and Acknowledgements

The region under consideration lies in the Northern Province of Tanganyika Territory in East Africa. It covers parts of degree sheets 12, 13 and 14. The task initially allotted to the writer, as a member of the Geological Survey Department of Tanganyika, was to geologically map on a reconnaissance scale of 1/50,000 all that part of degree sheet 13 which lay in Tanganyika Territory; that is 36° to 37° east; and 3° south, northwards to the Kenya border, an area of about 2,000 square miles. Subsequently, a geological survey of the whole of Lake Natron was required which necessitated a westerly extension from the 36° east meridian in order to incorporate the whole of the lake. The new western boundary was taken as the prominent scarp on the western side of the Gregory Rift Valley, adding an additional 550 square miles and several more volcanoes to the original plans. Some days were also spent in the plains to the north of the Kilimanjaro massif, east of the 37° meridian, when a further 60 square miles of terrain was geologically explored and mapped. The total area of about 3,500 square miles was covered in a little over 18 months field work.

As occasion demanded, and during local leave, investigations were carried out in some of the neighbouring areas covered mostly by volcanic rocks. These observations, together with notes made from an aerial reconnaissance, air photographs and borehole information, have all been used in helping to elucidate some of the geological problems of this area.

The detailed geological sketch map of what is considered to be the critical volcanological area, see fig. 1 , was subsequently compiled on a scale of 1/50,000. Traverses in the field were made using a prismatic compass, measuring wheel and aneroid barometer, and were supplemented by a plane-table network utilizing some of the suitable triangulation points of the German surveyors.

Apart from the Great North Road, which passes through the area and has recently been realigned with a tarmac surface, there are only a few bush-tracks. Porters are virtually unobtainable. Therefore, the region being situated in Masailand, whose people never undertake portering, it was imperative to move camp by lorry transport wherever possible. With care this was accomplished over most of the region, but a deplorable amount of time was spent on road-making and surveying a suitable alignment for the road. The most difficult localities for the lorry were found to be in the Lake Natron area, to the east of Gelai, and to the north and west of Engaro Naibor.

Almost all of this region falls into the Lake Natron Game Reserve, and rhinoceras and elephant are quite common in some parts; buffalo, lion and leopard were seen with scores of the more common and less aggressive wild animals. An African Game Scout was allotted to the party for protection purposes most of the time, as officially, only members of the Game Department are allowed to shoot in a Game Reserve. Tsetse flies, always the *longipennis* species were noted in some localities, and there are many mosquitos around the lagoons of the Lake Natron area.

There is a short rainy season during part of November and December, but at this time of the year, the dirt roads seldom become impassable due to the mud. The heavy rains fall between February and mid-May, when the dirt roads are often impassable, sometimes for several weeks at a time. The heat on the plains is never excessive, but down in the rift valley, especially in the Lake Natron area - the lowest part of the Gregory Rift Valley - the thermometer frequently goes over 100° F.

The physiography of the country is one of a modified pene- or pedi- planed surface at about 4,000 feet above sea level, with inselberges, all of basement complex rocks. This old shield area has been broken up by rift faulting, followed by volcanic activity. In the volcanological sense, the area is far from dead.

The drainage system consists of a series of inland basins, the most important being the Lake Natron area. Sweet water is extremely scarce, as soon as one ventures away from the flanks of some of the larger volcanoes.

Geological Sequence

The stratigraphy of this region is summarised below. The petrography and the relationships of the volcanic rocks form the main part of this work, although some attention has been given to the oldest rocks of the basement complex, and the more recent lake beds; which latter are frequently contemporaneous with volcanological activity.

These rocks and lacustrine deposits will be considered under the following headings:-

4. Lake Natron, lacustrine deposits.
3. Younger alkaline extrusives.
2. Older extrusives.
1. Basement complex.

Sedimentary deposits	Igneous activity	Igneous activity
4. Lake beds, Lake Natron	3. Younger extrusives	
Evaporite deposits	nephelinites, other alkaline rocks and carbonatites	
Shombole yellow arenaceous beds	Oldonyo L'Engai volcano	
Deltaic deposits	Kerimasi volcano (carbonatite)	2. Older extrusives
Magnesite deposits	Shombole volcano	andesitic - phonolitic types
Impure diatomite deposits	Mosonik ? volcano	Kibo crater on the Kilimanjaro massif
		? Mount Meru volcano
		? Gelai volcano
------ period of major rift-faulting, the Oldonyo Sambu fault ------ probably Upper Pleistocene		
diatomite		Kilimanjaro volcanoes
(Sambu volcanics)	Mosonik ? volcano	Mount Meru volcano
		Winter Hochland volcanoes
------ Kibangaini grid-faulting ------		
diatomite		Probably as above and ? Kibangaini trachytes
------ Malambo faulting ------		
(Sambu volcanics)		
diatomite with cherts		
(Sambu volcanics)		? Kibangaini trachytes
Green argillaceous beds		The Kilimanjaro volcanoes
Upper yellow arenaceous beds		Mount Meru volcano
(Sambu volcanics)	Mosonik ? volcano	Winter Hochland volcanoes
Lower yellow arenaceous beds		Gelai volcano
(Sambu and Mosonik volcanics)		Oldonyo Sambu volcano
		Ketumbeine volcano
------ rift faulting, including eastern step-faulting ------		
1. Basement Complex		

N.B. The exact dating of the older extrusives cannot be determined accurately, in all probability their horizons are something like those shown above.

Acknowledgements

I wish to acknowledge with gratitude the direction given by my supervisor of studies, W.H.Wilcockson Esq., Reader in Department of Geology at the University of Sheffield, who not only guided my thoughts and work at the University, but kept in touch during the field season of 1951.

At the same time, I acknowledge the many facilities of the Department of Geology at Sheffield University, placed at my disposal by Professor L.R.Moore, and for his encouragement in this work. I would also thank F.Wilkinson Esq., lecturer in the Department of Geology, Sheffield University, for many useful suggestions and constant encouragement.

The grant of a period of twelve months study leave without salary, by the Government of Tanganyika Territory is gratefully acknowledged. This period added to my own home leave enabled me to complete the necessary term of residence at the University of Sheffield.

I would like to record my appreciation to Dr.Max Coster of the Water Development Department of Tanganyika Territory, for permission to use relevant borehole information, and for personal encouragement in this work. The cost of nine new rock analyses by W.H.Herdsman of Glasgow, was met by the Department of Geological Survey, Tanganyika Territory whose financial assistance in this respect is gratefully acknowledged.

Appreciation is recorded of the close co-operation with T.Deans Esq., of the Mineral Resources Division, Colonial Geological Surveys, London, regarding the carbonatites. Permission was granted by Deans to quote certain mineralogical discoveries made by him. Some of these results were verified by X-rays by Dr.C.F.Claringbull of the British Museum.

I also acknowledge with gratitude the assistance of the Principal, Mineral Resources Division, Colonial Geological Surveys, London, and especially to W.H.Bennett Esq., who arranged for six rocks to be analysed, by R.O.Roberts Esq., and C.V.Green Esq.,.

Two partial analyses of rocks have been made by the Department of Glass Technology, Sheffield University, and I am grateful to Professor H.Moore, of that Department, and to the chemists concerned, for undertaking this work.

I have been encouraged in my work by G.M.Stockley Esq., and C.B.Bisset Esq., the former a retired Director, and the latter, the present Director of the Department of Geological Survey, Dodoma, Tanganyika Territory.

The photomicrographs were taken by Leitz equipment belonging to Mr.P.C.Sylvester-Bradley of the Department of Geology, Sheffield University, and I would like to record my gratitude for being allowed to use this equipment.

The Tectonic Pattern and the Age Question

Personal observations on the above subject have been recorded elsewhere in this thesis, see especially the section on Lake Natron. The following remarks, therefore, are more in the nature of a synthesis of existing information with the inclusion of personal views.

In 1936 Professor Bailey Willis[1] in his exhaustive work on the structural problems of East Africa, summarised existing knowledge up to that date, adding his own observations and conclusions. He personally visited the Malambo area of Lake Natron, which he described thus:-

"The area is the lowest part of the rift valley.......the surrounding district is a desert plain, broken by ridges of black lava and overlooked by high volcanic cones. It is the most desolate, burnt, and dessicated landscape in East Africa".

Bailey Willis refers frequently to Lake Natron (pp.58 and 200) and on several occasions quotes from Carl Uhlig, one of the early German explorers, who was also a cartographer. All relevant structural knowledge, together with additional new evidence, has been incorporated in the sketch map fig. 3 .

A study of this sketch map indicates that besides the well known Gregory Rift Valley faults there are also present several additional different types of faulting, which are considered under the following headings:-

1. The western escarpment of the rift valley.
2. The eastern step-faulted region of the rift valley.
3. The east-west faulting.
4. The Kibangaini grid-faulted area.

The following points require further elucidation:-

1. The relationship of faulting and volcanism.
2. The age question.

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(1) Willis, Bailey, 1936. East African Plateaus and Rift Valleys. Carnegie Institute, Washington. No. 470.

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Poor text in the original thesis.

1. <u>The Western Escarpment of the Rift Valley</u>

The faulting appears to have been greatest on this side of the rift valley, and the escarpment is frequently referred to as the rift wall. Evidence has been submitted in the Lake Natron section, indicating the writer's full agreement with Bailey Willis's[1] interpretation of the faulting on this western side of the lake. There are two faults, the younger and more easterly, the Oldonyo Sambu escarpment in the north, and the older, the Nalembo scarp to the south and west which is cut off by the first Sambu fault. In the [illegible] corner of L. Natron is another fault scarp called by Uhlig the Sonjo fault. [illegible] this [illegible] is around [illegible], but changes to a more northerly direction north of the Kenya border. It is also thought to be older than the Sambu fault.

It has been postulated in the Lake Natron section, that the younger Sambu fault, may probably be correlated with the Angaruka fault, which lies in a direct southerly line of continuation of the Sambu fault. Both scarps attain a height of between 3,000 to 4,000 feet or more in places, and are remarkably youthful features. If the Oldonyo Sambu-Angaruka fault belongs to one and the same fault system, then the line of faulting passes that part of Lake Natron, nearly under the centre of Oldonyo L'Engai, still an active volcano, and thence southwards under Kerimasi, emerging further southwards, as the Angaruka escarpment.

Dealing with the Gregory Rift Valley as a whole, Bailey Willis[1] discusses at some length the western faults of the rift valley, which to the writer appeared to be normal faults. Although Bailey Willis was unable to visit the north-west corner of Lake Natron, he quotes Uhlig[2] at length, who brought forward evidence for overthrusting in this area.

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(1) Willis Bailey 1936. East African Plateaus and Rift Valleys. Carnegie Institute, Washington. No. 470

(2) Uhlig C. 1907. Die sogenannte Grosse Ost-Afrika Graben. Geogr. Z. Vol. 13.

According to Bailey Willis[1] this is the only occurrence of thrust faulting in the Gregory Rift Valley, and hence, if proved correct, is of unusual importance and interest.

The writer visited the area, which lies on the Kenya border, and climbed the escarpment in three places in an attempt to try and verify Uhlig's[2] observations. No real conclusion can bedrawn without some detailed geological maping in this region, but, having seen something of the evidence, it is felt that the second proposal put forward by Bailey Willis, with regard to the origin of Uhlig's thrust fault, is nearer to the truth, namely that:-

"the supposed overthrust is a case of intrusion of sheets and dykes along the foliation planes of the ancient structure."

It is indeed a fact that whilst climbing and descending the scarp, in different places, basement rocks can be seen overlying the much younger "lava" It is confirmed that the basement quartzite is sheared and micaceous in this region, but not to any unusual degree, and it is felt that its present position is more likely to be due to the fact that rocks associated with the volcano of Oldonyo Sambu are intruded beneath it.

The acknowledged fact that half of this volcano now lies down-faulted under Lake Natron, means that there are exhibited in the existing fault scarp, some of the intrusive dykes and sills from Oldonyo Sambu, which would otherwise not have been visible. The volcano had to pierce through the basement rocks before it could build up its volcanic cone on the upper basement surface. Therefore, as this point seems to be near the junction of basement and lava flow, the Sonjo scarp is mainly in the basement rocks - it is then quite logical to find some of this basement country rock now situated on the lower northern flanks of the volcano looking as if it had

(1) Willis Bailey 1936. East African Plateaus and Rift Valleys. Carnegie Institute, Washington. No. 470.

(2) Uhlig C. 1907. Die sogenannte Grosse Ost. Afrika Graben. Geogr. Z. Vol. 13.

been thrust over the "lavas" by pressure from a northerly direction, whereas actually, all movements of the basement were controlled by the ascending lava.

Detailed mapping alone will prove this point although in all probability similar effects should also be noted in other areas where isolated volcanoes have pushed their way through the basement cover, and now stand as does Hanang, well to the south, a volcanic cone amongst basement gneisses and schists.

2. The Eastern Step-faulted Region of the Rift Valley

Many of the early German explorers in the Lake Natron - Oldonyo L'Engai-Engaruka area, were impressed by the scarp feature on the west side of the rift valley and recorded, that by comparison, there was no similar feature on the eastern side of the rift valley. Uhlig's description quoted by Bailey Willis(1) (p.203) depicts a series of mature faults, scarps and steps, on this eastern side. In one place Uhlig noted four such benches, or steps, the final one coinciding with the normal unfaulted but locally tilted peneplain. The width of the rift valley floor in this part of the Gregory Rift Valley, is of the order of 25 miles.

There is little that can be added to Uhlig's remarks, except confirmation of his observations, and the statement that anyone travelling on the motorable track from Longido to Ketumbaine or Gelai, would be impressed by these benches whilst descending to the floor of the rift valley.

When tracing these step-faults further to the south, Uhlig says that they eventually disappear, and with them the east wall of the graben. This is not strictly correct, as from field work, aerial observation, and borehole evidence, it appears that some of these faults swing to the east, and can be continued in the manner shown on fig.3. Some of these fault lines, if projected eastwards, appear to run under the Kilimanjaro massif, whilst other faults noted in

(1) Willis Bailey 1936. East African Plateaus and Rift Valleys Carnegie Institute, Washington. No. 470.

the field and from the air, with a more southerly direction would pass near Mount Meru. As morphological features, these scarps today are nowhere so impressive as the original step-faulting further north, and in the south the width of the actual steps probably increases. Present day relief indicates that at one time these scarps may have been imposing features, which have been obliterated by the subsequent outpourings of lavas from the numerous volcanic necks in the vicinity. Here then, is evidence that some if not all of the step-faulting occurred before the lavas were extruded. In the latitude of 5° south, and west of the Great North Road, some of these lava flows are also step-faulted; apparently, much smaller movements along the older fault lines.

Recent borehole evidence is relevant and gives additional confirmation on this subject. All boreholes were put down by the Water Development Department of Tanganyika, and the writer again gratefully acknowledges the assistance of Dr. Max Coster, the Chief Geologist of this Department who has allowed the use of this information.

One borehole, B.H. 4/39 (borehole no. 4. of 1939) was sunk to 550 feet in the "Lower" Basement complex. Eight miles further south, however, another borehole, B.H. 8/39, was drilled to a depth of 425 feet in broken lava, apart from surface soil and broken limestone, up to a depth of 15 feet. Actually, both of these boreholes were drilled near to the Great North Road, and on this road which is otherwise remarkably level, and between the two borehole sites, there is an abrupt rise: this is considered to represent one of the step-fault scarps, now with a completely changed direction from north-south to west-east. Other faults running in this latitudinal direction are considered below.

One further point, however, should be made, and that is it is very noticeable, especially in the north of this region, that having ascended to the uppermost step of the step-faults, the peneplain is downtilted towards the east for a matter of twenty miles, before joining the actual untilted or less tilted and unfaulted peneplain surface at a height of between 3-4,000 feet above sea level.

5. The East-west Faulting

Having travelled southwards from the Kenya border and established evidence of an east-west fault system in the latitude of 3° south, it is natural to continue southwards in the search of some such complementary parallel fault system.

In the field (1) part of a basement scarp trending approximately NE/SW in the Shambarai area was mapped, and found to be a scarp which frequently changes direction; near Sochi it runs almost east-west. Further noted in the field although not actually mapped but clearly shown on the topographical maps - to the west, the Shambarai scarp changes direction to WNW/ESE. The old basement scarp to the south of Mount Meru is irregular, but in places does run east-west.

Once again additional evidence is obtained from borehole records, and the geological results and significance of B.H. 6/48, which penetrated lava to a depth of 1,065 feet, were noted in the Annual Report of the Water Development Department in 1948. The thickness of individual lava flows does not seem to exceed 45 feet, the report states, and estimates a downthrow for the basement, of between 1,100 to 1,300 feet. In this report, Dr.Coster suggests that "this faulting must have taken place early in the development of the rift valley during the period of plateau lava flows". There is no evidence regarding the direction of this fault, except that the nearest basement to the south is a scarp face trending approximately west-east.

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(1) Guest N.J. Shambarai dolomitic crystalline limestone and graphite. M.R.P. No. 50. Dept. of Geol. Survey. Tanganyika.

Between these two faults, now largely obscured by the more recent extrusive rocks, is a line of weakness, on which at least six volcanoes are situated; this line of weakness was noted and commented on by the early explorers. At the eastern extremity of this line stands the highest volcano or group of volcanoes in Africa, the Kilimanjaro massif, 19,565 feet, and at the western end, one of the smallest volcanoes in this region, Essimingor, 7,140 feet.

It would appear from the above, that there may be evidence for an east-west subsidiary, smaller "rift valley", now largely infilled by the older lavas, and joined to the north-south Gregory Rift Valley at its western end.

6. <u>The Kibangaini Grid-faulted Area</u>

The term "grid-faulting" was introduced by Prof. J. W. Gregory, for the type of faulting to the north of Lake Natron, in the Lake Magadi area. Bailey Willis(1) reports (p. 204) that Gregory described grid-faulting as "that condition by which the valley floor is divided into narrow strips which rise to different elevations, and are bounded by nearly vertical walls. He compares (grid-faulting) with railway platforms between relatively low tracks", where, around Lake Magadi - and Lake Natron - the vertical displacements of the strips are in no case over 100 feet, and usually much less.

An identical pattern of grid-faulting was noticed to the south of the Kenya border, in the Kibangaini area, obviously an extension of the Magadi grid-faulting. Bailey Willis states that in the Lake Magadi region, the grid faulting terminates at each end in a volcano, and he uses the rather apt analogy, of the "faults dying out just as a split fails

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(1) Willis Bailey 1936. East African Plateaus and Rift Valleys. Carnegie Institute, Washington. No. 470.

to pass through a knot in a plank". To the south of Lake Magadi, the "knot in the plank" is represented by the Lenderut Hills, thence further southwards lies the area of the Kibangaini grid-faults, which themselves are partly terminated on the north side of Gelai, but were noted running southwards on the east side of this volcano.

These grid-faults are small features considered to have no great throw, and therefore, at the moment, it does not seem necessary to venture into the sub-stratum for a mode of origin, unless such a mode of origin cannot be proved satisfactorily by other means.

If it is correct to state, as has been advanced in the Lake Natron section, that the Oldonyo Sambu fault is of a trap-door nature, then the Kibangaini grid-faulting may well represent the hinge-line of this trap-door. In this case the grid-faulting is perhaps more a tensional than a compressional feature. On the other hand, if the grid-faults are not connected with the Sambu period of faulting, then it seems they would best be explained as a series of horsts and gräben caused by compressional forces. It is stressed that these ideas are, at the momen speculative, but if the latter mode of formation is correct, then, as Oldonyo Sambu appears to be a normal fault of tensional nature, we have two opposite forces at play, at different times in the same portion of the rift valley.

Bailey Willis[1] (p. 68) considers grid-faulting to be "the expression of normal faulting on a fluid support".

The Lake Natron grid-faulted area slopes downwards from east to west, and all the faults appear to be normal ones, with no sign of increased faulting or change in hade towards the lake shore. It has been suggested in the Lake Natron section, that the grid-faulting of the Kibangaini area, is probably older than the Sambu faulting, although, in Kenya,

(1) Willis Bailey 1936. East African Plateaus and Rift Valleys. Carnegie Institute, Washington. No. 470.

several periods of grid-faulting have been noted.

1. The Relationship Between Volcanism and the Faulting

Two of the important areas indicated as rift valley volcanics on the latest geological maps of Tanganyika occur:-

1) In the Oldonyo L'Engai area.

2) In the Mbeya region of S. Tanganyika.

In both cases these volcanoes are situated at the bifurcation of a rift valley fault system. When the tectonic pattern of the first region is analysed as a whole, it can be demonstrated that faulting and volcanism are generally closely related, and that volcanism results after faulting, although this need not be the case in other areas.

Oldonyo L'Engai, the active volcano is situated as the map fig. 3 . shows, at the focal point of the Eyasi Rift Valley and the Gregory Rift Valley; if the Eyasi Rift Valley is projected northwards beneath the younger lava massif of the Winter Hochland which now largely obliterates any sign of it. Field evidence shows that it is indeed permissible to project the Eyasi rift faults as stated, because of a series of small volcanoes, mostly of the older extrusive rock types, stretching along a line from near the summit of Gelai, southwestwards, to between Oldonyo L'Engai and Kerimasi; a line which if continued in the same direction, passes into the Lake Eyasi rift valley.

Similarly, it was noted, that if the Sambu fault is correlated with the Engaruka fault, then this fault passes beneath Oldonyo L'Engai, and Kerimasi. The active volcano therefore, occurs at the meeting place of certainly two, and probably three, large fault systems.

Another perhaps more obvious example of this tectonic and volcanological relationship, is seen in the Kilimanjaro massif. Here the Pare mountains have been referred to as a block mountain, while the fault scarps of this horst, when projected under the Kilimanjaro massif, where they appear to terminate, meet the marked line of weakness, joining at least six other volcanoes, and the easterly trending step-faults of the Gregory rift valley.

There may well be some significant correlation possible between the several grid-faulted areas of E. Africa in which trachytic rocks seem to occur abundantly.

2. The age question

Dr.R.B.McConnell(1) has recently postulated that the origin of the East African Rift Valleys is due to dextral tear-faulting at the close of the Ubendian cycle of the Pre-Cambrian, and states:-

"the present rift valleys are regarded as revivals of thesemovements."

In the Oldonyo L'Engai area, the only method of dating at present available, is by comparative morphology, and in this respect the history of the region can be summarised thus:-

1) The step-faulting in most places is pre- the older extrusives. After this step-faulting of unknown age, there occurred a period when:-
2) The older extrusives, namely volcanoes such as Gelai, Ketumbaine, Meru, Kilimanjaro massif, and the Winter Hochland volcanoes, all commenced erupting. Mosonik, considered here to be of younger extrusive rock-type - a point dealt with later under petrogenesis also appears to have started erupting. This is interrupted by the formation of:-
3) The Malambo, western rift fault, possibly associated with grid-faulting, and perhaps some step faulting of lesser importance.
4) At this stage Oldonyo Sambu, and other older lava type volcanoes continue erupting, whilst Mosonik possibly continues to erupt younger

(1) McConnell R.B. 1948. Rift and Shield Structure in E.Africa. Int. Geol. Cong. Pt. XIV p.199.

types of lava. This is followed by:-

5) Major Sambu faulting which has been shown in the Lake Natron section to be probably of Upper Pleistocene age and possibly the Kibangaini grid-faulting.

6) Then followed the last volcanic episode, consisting essentially of the eruption of the younger soda-rich lavas. Possibly Mosonik still erupted, while Shombole, Kerimasi, and Oldonyo L'Engai certainly erupted. Kerimasi's extrusives partially obliterate the newly formed scarp north of Engaruka. All of these volcanoes, except Mosonik rise from the rift valley floor.

It is obvious from the above that rift faulting and volcanism are closely related, a point which is taken up later more fully under the section on petrogenesis.

Basement Complex Rocks

Details of the rocks in the oldest system in this area are beyond the scope of this thesis. Attention should be directed to them, however, in so far as they concern the problems relevant to the more recent extrusives which have had to force their way through these basement rocks, and to the structure of these rocks, which is incorporated in the tectonic pattern of the area as a whole.

These basement rocks have all been thoroughly altered, so that any trace of bedding has yet to be noticed. The rock types and mineral assemblages are extremely variable, with almost every gradation from one type of gneiss or schist to another.

Of particular interest however, is the presence of a belt of crystalline limestone, see fig.2, from Naberera in the south, where wells have been dug in the crystalline limestone, northwards to Shambarai. Here dolomitic crystalline limestone with graphite bands were reported[1] in August 1950. Three interesting analyses from this locality are as follows:-

TABLE NO. 1

	JG023	JG030	JG034
Loss on ignition	41.8%	34.6%	46.6%
Insolubles in HCl	11.0	25.0	1.6
R_2O_3	1.2	0.9	0.7
CaO	27.6	23.6	30.5
MgO	18.5	14.9	20.6
	100.1	99.0	100.0

Analyses by Dept. of Geological Survey, Tanganyika. Ref. K/2512.

Most of the insoluble matter was quartz, and all limestones consist of dolomite very close to the theoretical ratio of CaO/MgO.

(1) Guest N.J. The Shambarai Dolomitic Limestone and Graphite. Mineral Resources Pamphlet No.53. Dept. of Geological Survey, Dodoma, Tanganyika.

Comparable analyses of dolomitic crystalline limestone from the basement complex of the Iringa District, over 400 miles to the south show:-

TABLE NO. 2

	JG51	JG121
Loss on ignition	46.3%	25.8%
Insolubles	2.0	33.7
R_2O_3	.7	2.1
CaO	30.6	17.7
MgO	20.7	20.9
	100.3	100.2

Analyses by Dept. of Geological Survey, Tanganyika. Ref. X/2108.

Other outcrops of similar crystalline limestone can be seen to the NNE along the road going southwards from Sanya. These outcrops are believed to join the Shambarai dolomitic limestone. Immediately northwards the lavas of Kilimanjaro and Meru obliterate the basement, but to the north of these volcanic mountains, crystalline limestone was mapped on the "Seven Sisters" hill, marked Leirugorugo on the German map of the Kilimanjaro area. An analysis of a rock (JG1453) from this locality, shows very low MgO, whereas two other analyses (JG1450, JG1460), of secondary limestone, from the adjacent Sinya area, show higher MgO. From field evidence it was postulated that the limestone from "Seven Sisters" hill, and the limestone underlying this area, as proved by borehole 28/40 of the Water Development Department of Tanganyika, provided the source of origin for the Sinya secondary limestones.

TABLE NO. 3

	JG1453	JG1450	JG1460
Insolubles	0.2%	15.3%	15.7%
R_2O_3	0.1	0.6	1.0
CaO	50.7	24.8	23.1
MgO	4.7	27.0	18.7
Loss on ignition	44.3	31.4	41.6
	99.9	99.0	100.1

Analyses by Dept. of Geological Survey, Tanganyika. Ref. X/2057/3

The above analyses indicate that all basement crystalline limestones of this region are not dolomitic, although the majority contain over half as much MgO as CaO.

Just south of Kajiado, over the Kenya border, and almost due north of the Neberera-Shambarai line, mentioned above, crystalline limestone is actually being quarried.

More detailed mapping will help to fill in the gaps in the present geological knowledge, but reconnaissance geological mapping does indicate the existence of a possibly continuous belt of crystalline limestone, generally dolomitic, trending north-south, which may well extend further in both directions. Smaller occurrences of crystalline limestone were mapped to the west of this main limestone belt, in the step-faulted region of the basement complex - the eastern rift wall. Graphite was also located in some places in the same area.

During the 1960 field season, of the 365 readings taken on the lineation of the basement rocks in this area, 201 fell between the direction 205/025° and 240/060°, indicating a general north-easterly trend for the lineation. All the above occurrences appear to fall into Prof. A. Holmes's(1) Mozambique Belt, which trends approximately north-south with local variations.

Summarising the above, it is important to note that, certainly approximately 70 miles to the east of the occurrences of alkaline rocks, and much less in some cases, there appears to be a belt of crystalline limestone, generally dolomitic, running approximately parallel to the Gregory Rift Valley.

The possible significance of this is considered more fully later under the heading of petrogenesis.

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(1) Holmes A. The sequence of Pre-Cambrian orogenic belts in South and Central Africa. Int. Geol. Cong. 1948. Pt.XIV. p. 254.

The Older Extrusives

General Introduction

Intermediate in age between the basement system and the younger alkaline extrusives, but more closely related to the latter in age and petrology, are a suite of rocks including mostly andesitic and rarer basaltic types. They consist of calc-alkaline and alkaline types, but are nowhere as alkaline as the younger extrusives considered later.

Rocks of these types make up the rift wall in three places:-

1. In the SW from near Engaruka to Kerimasi.
2. From the north side of Kerimasi, to where the Mosonik lavas have been poured over them further north.
3. Southwards from the Kenya border, in the NW, and associated with volcano of Oldonyo Sambu, to where they are overlain by the northern Mosonik alkaline lavas.

On the east side of Lake Natron, there are also three different occurrences of the older lavas:-

4. In the south, the old volcano of Ketumbaine.
5. North of Ketumbaine, another extinct volcano called Gelai.
6. North of Gelai to the Kenya border, the Kibangaini trachytes.

These six areas will shortly be considered individually.

Observations on the old volcanoes of Ketumbaine and Gelai have enabled a general succession of lava types to be established. The older lavas of Ketumbaine are andesitic with intercalations of mugearite, and are succeeded by trachyandesite with large phenocrysts of plagioclase; a rock type characteristic of the Mawenzi peak on Kilimanjaro and referred to hereafter as the Mawenzi-type. More nephelinitic types occur as parasitic cones on and around the base of Ketumbaine.

As will be shown later, the outpourings of Golai are younger. These begin with nepheline sola-basalts which are followed by phonolitic trachytes and trachytes that make the summit of the mountain.

As an example of the basic andesitic rocks of Kotumbaine, the specimen JC830 may be described. Macroscopically this is seen to be a dark coloured rock with a distinctly flaggy habit; small crystals, probably feldspar, show reflection from cleavage faces. Microscopically it is seen to be a moderately fine grained rock, with feldspar laths of approximately $Ab_{50}An_{50}$ composition, the larger feldspars being the more basic. Slightly purple coloured pyroxene is present with many small granules of olivine, a fair amount of magnetite, and very altered remains of olivine associated with a greenish brown decomposition product, where the green material looks like serpentine. The rock is an andesite with more basic feldspars. An example of a less basic andesite is JC1296, which macroscopically is a grey coloured rock, although not so light in colour as JC801 - shortly to be described. It is fine grained, compact, and shows slight vesicular texture, and banding on a small scale. Under the microscope it is seen to be a fine grained rock consisting of small laths of andesine, showing a distinct flow texture, associated with very pale yellow green clino-pyroxene, and small partly decomposed olivine, yellow-brown in colour, and there is a fair amount of granular magnetite present.

A somewhat different rock is JC1295, collected higher up the mountain than JC1296. In the hand specimen it is a fine grained, dark grey rock, with small feldspars, mostly considerably altered, and yellow in colour; the rock has a tendency to be slabby. Microscopically, it is a very fine grained rock with microphenocrysts of oligoclase, and fragmentary remains of a deep brown hornblende often associated with magnetite. The very fine grained ground mass consists of small needles of oligoclase, exhibiting good flow texture;

iron ore, and very fragmentary pale yellow-green patches with R.I. above balsam, possibly volcanic glass; together with brown patches, probably iddingsite after olivine. The sodic feldspars show this rock is allied to the mugearites.

A typical trachy-andesite, collected 500 feet below the crater on Kotumbaino, is JG1501. Macroscopically, it is a distinctive, grey, vesicular rock, with abundant large platy plagioclase embedded in a very fine grained ground mass. Microscopically, the larger feldspars are seen to be labradorite or basic andesine, at times zoned with peculiar effects. In one case, the extinction angle diminishes towards the periphery therefore, becoming more sodic, yet the centre of the crystal is a little more sodic than the most calcic border zone. The ground mass consists of slightly more sodic andesine feldspar in small laths often showing trachytic texture, associated with common, small, granular olivine, the latter occurring rarely as microphenocrysts, when they are considerably altered to iddingsite. Small fragments of faintly green yellow coloured pyroxene with wide extinction angle, and rarer small fragments of a dark brown mineral, possibly hornblende, and a fair amount of granular magnetite also occurs in the ground mass.

This is a typical Mawenzi-type trachy-andesite; sometimes these rocks are more basaltic, and should be compared with a similar rock (JG1611) from the type locality, the Mawenzi volcano on the Kilimanjaro massif.

Examination of the thin section shows JG1611 to be slightly larger in grain size than JG1501, and it contains more ore. The larger olivines have now gone over to iddingsite almost completely, and the pyroxene has a purple tint. The plagioclase phenocrysts are not quite so fresh as in the Kotumbaino rock.

A variety of the Mawenzi-type trachy-andesite, JG1502 from some 2,000 feet lower than JG1501, contains more iron ore, less pyroxene, some distinct deep brown hornblendes, and many smaller plagioclase phenocrysts of a more sodic variety of andesine.

Now follow descriptions of three rocks typical of the more nephelinitic types and belonging to the parasitic cones, around or on the base of Kotumbaine, although similar types have been noted elsewhere.

In the hand specimen, JG891 is a very fine grained rock, grey in colour and showing distinct banding and rare large feldspars. Micro-scopically, the rock is fine grained with small laths of sodic plagioclase, generally with indefinite nearly straight extinction, together with much granular olivine of yellow brown colouration, in part due to decomposition, and small colourless clino-pyroxene fragments with a fair amount of granular anhedral magnetite. Interstitially there is much feldspathic material and some nepheline. These rocks cannot be well classified as basanites, as the feldspar is too sodic, and may be referred to nepheline-andesites as defined by Johannsen[1]. This rock is, therefore, a non-porphyritic nepheline-andesite.

From the parasitic cone called Lolgurdolgonja comes a rock which is typical of Golai and much of the rift wall. Macroscopically, JG707 is a dark purple grey rock with phenocrysts of pyroxene and altered olivine; possible zeolite with some calcite and magnetite are present in smaller amounts. In thin section the phenocrysts of clino-pyroxene are light brown to green in colour, with darker coloured borders showing slightly smaller extinction angles; the core of these phenocrysts often contains much granular magnetite and small olivines. There are rarer large olivine

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(1) Johannsen A. Descriptive Petrography IV.

phenocrysts, rimmed by a yellow brown decomposition material which also occurs along cracks in the crystals, and interstitially amongst the olivines in the ground mass. Together with the olivine in the ground mass is much granular magnetite, and small fragments of pyroxene. Interstitially there is a little nepheline, seen better in section of J0703, and some calcite and zeolites are present in cavities. Feldspar is absent. The rock is called a nepheline-melabasalt.

In the hand specimen, another rock J0800 from the same locality, is dark green in colour, compact, with small black phenocrysts of pyroxene, and more abundant, euhedral, small nephelines, embedded in a very fine grained dark matrix. Some granular black ore is visible. The rock becomes lighter green on the weathered surface. Microscopically it is similar to the nepheline-melabasalt in that it contains phenocrysts of clinopyroxene and less common olivine; in additon nepheline occurs as phenocrysts. The pyroxene has a faint green colouration, and the olivines are very much altered to iddingsite, and are commonly entirely enclosed by nepheline; whilst elsewhere in the same slide olivine sometimes encloses small areas of nepheline. The ground mass is fine grained and dark: euhedral nepheline and magnetite are common, and the darker material consists of much finer grained ore, pyroxene and olivine; all are embedded in interstitial nepheline. There are also larger patches of yellow green isotropic mineral, with very low R.I., possibly analcime. Some small laths of feldspar with almost straight extinction are to be seen under high power. This rock has been called a nephelinite with phonolitic tendencies.

Although most of the above rocks were collected from Kotumbaine, similar types were noted in other localities, but hereafter, only the unusual petrographic points will be described. The more siliceous trachytic types are described under the Gelai lavas and Kibangaini trachytes.

The distribution of the rock types in the several areas will now be described.

1. <u>The Rift Wall: Kerimasi Southwards To Near Engaruka</u>

In order to obtain a general idea of the more andesitic rock types, it is necessary to consider briefly the rocks making up the base of the scarp face of the western rift wall in the area as a whole. Here, the volcano of Kerimasi is younger than the rift wall as it has erupted over it.

Apart from the small hill called Mosota, composed of calcareous tuff and situated near the road leading northeast from Engaruka, which will be considered along with Kerimasi later; the rocks of this small region may be divided into two distinctly different types. The alkaline ejectamenta of the sunken crater called Embagai, north of Engaruka, and the more andesitic rocks of the rift wall proper.

Actually, only the base of the rift wall was examined, and the lavas for the most part have come from the "Giant Craters" of the volcanoes to the west situated above the rift wall, and forming collectively the upland area known as the Winter Hochland.

To the south of Engaruka river, the rocks vary slightly compared with those to the north; but the andesitic types as a whole are distinctive in that many of them include brown hornblende, at times in fair quantity.

To the south of the river hornblende was noted in most of the rocks collected, but in the extreme south, large augite phenocrysts become the most interesting feature. Here many large and small augite crystals were collected, whilst traversing along the small scarp trending east and then southwards. These augites had weathered out of the andesitic rock-types which sometimes showed an affinity to the Lemonzi-type trachy-andesite. Some augite crystals

(JG705) measured just under 3 inches along their c-axes.

At least two rock specimens have distinct nepheline-basanite tendencies, rich in olivine, and comparable to similar rocks from the lower flanks of Gelai, and to the rift wall north of Kerimasi. These rocks are called nepheline-melabasalts since feldspar is lacking.

To the north of the river, nepheline is distinctly seen in JG707 and JG770, exhibiting a phonolitic-nephelinite tendency. These more alkaline rocks, tend to occur in small hillocks of volcanic cones or domes, along the base of the rift scarp, and may well represent cones of fissure eruption; the fissure in this case being the fault plane.

Olivine and hornblende persist, and a Mawenzi-type resemblance has been noted in other rocks. As a whole, the rocks seen in this part of the scarp range from andesitic types to nephelinites. Some of the andesites have porphyritic augites, others exhibit marked flow texture, and the Mawenzi-type trachy-andesite is also represented. Rarer, but also present are nepheline-andesites, nephelinites and phonolites.

The specimens collected from Embagai are of a completely different nature to any of the above, and belong to the more sodic series, where nepheline and aegirine-augite predominate. Slices show beautiful zeolite formations infilling cavities, and possible sodalite. These rocks belong to the younger alkaline extrusives considered later.

2. <u>The Rift Wall, North Of Kerimasi To Mosonik</u>

Where the rift wall emerges from the north side of the Kerimasi extrusives, the rock types continue to resemble those found immediately to the south of this volcano, though hornblende is noticeably rarer.

The base of the rift wall consists mainly of nepheline mela-basalts, rich in olivine, as noted to the south and at Gelai. Small hills along the base of the scarp consist of different rocks, and one specimen (JG941) is a peculiar spotted rock in the hand specimen: the black spots are distinctive, and the general slabby nature and tendency to form a sharp edge on a fractured surface, suggests alteration by contact metamorphism, possibly by a subsequent lava flow. The slide shows only rare small phenocrysts of very altered olivine, which may represent the black spots seen macroscopically. Nepheline is present, and the rock is more phonolitic in type, comparable to those to the south, and possibly also a product of fissure eruption.

Along the base of the rift wall in the Oldonyo L'Engai locality, numerous ejected fragments were noted, together with buff or yellow coloured agglomerate and grey-ash, typical of Oldonyo L'Engai.

To the north of Oldonyo L'Engai, rocks similar to those forming the base of the rift wall to the south were collected, and in one place a typical nepheline-melabasalt (JG911) was found overlying a more andesitic rock, but with distinct nepheline-andesite tendencies (JG910). The presence of nepheline in the latter specimen was proved by gelatinizing and staining.

In this area the dips of the lava flows are almost horizontal, but the land surface to the north slopes downwards towards the shore of Lake Natron; so it is only here, that the succession nepheline-melabasalts overlying andesites can be seen. Similar trends are noted elsewhere where an andesitic type with basanitic affinities, grades into an overlying nepheline-andesite type.

5. <u>The Rift Wall, Southwards From The Kenya Border To the Lavas Of Mosonik</u>

This part of the western rift wall embraces the lavas of the old volcano of Oldonyo Sambu. The rock-types present are described in some detail in the Lake Natron section later, where a review of the outcropping rocks surrounding the lake were undertaken, in an endeavour to establish a possible petrographic correlation between the lavas of the western rift wall, with those to the east of Lake Natron.

The rocks are of similar types to those noted elsewhere on the western rift scarp. In common with the volcano of Ketumbaine, and the rift wall south of Engaruka, this district contains trachy-andesites of the Mawenzi-type. These show gradations to more basanitic rocks, or andesine-nephelinites, through the incoming of nepheline; and trachy-basalt and andesitic types through the decrease in feldspar phenocrysts, the presence of more sodic plagioclase, and the general smallness of grain size. Although no stratigraphy has been worked out on the Oldonyo Sambu lava flows, it is perhaps permissible, at this stage, to suggest Oldonyo Sambu may have been contemporaneous with Ketumbaine, in view of the predominance of Mawenzi-type trachy-andesites amongst the lava flows of both of these volcanoes.

The following rock types are common to this part of the rift wall and Ketumbaine. Andesite with porphyritic olivine and augite, andesite with trachytic texture, nepheline-andesite, and the abundant Mawenzi-type. Nepheline-basalts are rarer, and nepheline-tephrite was noted in the Malambo area, south of Sambu, but was not found on Ketumbaine. More normal andesites, however, were only found on Ketumbaine.

4. <u>The Old Volcano Of Ketumbaine</u>

What is considered to be the oldest lava flow mapped on the flank of the volcano is an andesite with basic plagioclase, a rock noted at several localities around the base of the mountain. Olivine and pyroxene are always abundantly present, and in some specimens occur as phenocrysts; the feldspars generally show Mawenzi-type affinities. Typical examples are JG 806, 805, 1317.

Ascending the mountain on the western flank, andesitic types appear to persist upwards to about 6,000 feet; at times (J01304) faintly resembling the Mawenzi-type, noted near and on the summit of the volcano, while elsewhere, the rocks on the lower flanks have nepheline-andesite tendencies. At 6,000 feet the lava was an andesite (J01296) with marked flow texture, but devoid of plagioclase phenocrysts.

Higher on the north-west flank, at about 6,500 feet (J01295) and at about 7,100 feet (J01299) finer grained trachytic rocks were collected, which continued to show a tendency to develop the large plagioclase phenocrysts of the Mawenzi-type, except that the plagioclase now becomes the more sodic oligoclase, and the rocks therefore allied to the mugearites.

At about 7,200 feet several traverses were made from the bivouac camp, around the mountain in both northerly and southerly directions; similar Mawenzi-types and andesitic rocks at times showing affinities leading to the Mawenzi-type, were collected.

On the north-west flank of Ketumbaine, the same rock types persist upwards from about 7,200 feet to 7,400 feet. At 7,200 feet a specimen (J01293) showed slight affinities towards the overlying Mawenzi-type, but contained more sodic-plagioclase, andesine, and some slightly larger olivines.

A typical Mawenzi-trachybasalt (J01300) was collected from the north-westerly crater rim of the old volcano of Ketumbaine at a height of 9,000 feet. Some 500 feet below, a further specimen (J01301) was found and the large platy sodic-labradorite plagioclase can be seen in both macrospecimens. Most plagioclase feldspars in J01301 are zoned, and have been described in more detail above. At 7,400 feet (J01303) the feldspar becomes slightly more sodic, strictly andesine.

Around the base of Ketumbaine, at least, on the western flank, two other rock types were noted. The first is a nepheline-andesitic type (JG 801 and 803) with at times affinities towards the Mawenzi-trachy-andesite, and associated with small parasitic cones. Overlying this nepheline-andesite in one place on the west flank of the parasitic cone, Lolgurdolgonja, the other type was located. It is an olivine-rich feldspar free rock, referred to nepheline-melabasalt (JG797, 799) and is associated with other rocks with distinct phonolitic and nephelinitic tendencies (JG803). The relative age of the nephelinitic rock (JG800) is not known it was found at a lower altitude than the melabasalt.

Most, if not all of the above specimens found on the lower flanks of Kotumbaino, belong to small parasitic or subsidiary cones formed later than the outpouring of the Kotumbaino mafic andesites, whichappear to form the base of the mountain. These younger olivine-rich nepheline mela-basalts, resembling to some extent the Atlantites of Lehmann(1) from Nyasaland and Southern Tanganyika, are very like some of the Gelai rocks. The nepheline is often difficult to detect under the microscope, but gelatinization in hot conc. HCl fumes, and subsequent staining by malachite green, reveals its presence.

The small parasitic cone of Lolgurdolgonja, forming a marked feature on the lower western flank of Kotumbaino, looks morphologically young, and may represent an even later extrusive phase of this Gelai-type magma. The fact that it is associated with nephelinite type rocks, not yet noted on Gelai, adds some significance in this respect.

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(1) Lehmann E 1923. Zeitschr of Vulkanologie. Erg.IV.

Although detailed investigation of the individual lava flows may modify the results so far obtained, a general magmatic trend can be outlined as follows:-

<u>Lolmurdolronia</u> subsidiary volcanic cone

Nephelinitic-phonolite.

Nepheline-melabasalt. (Gelai type).

Nepheline-andesite. (aff. Mawenzi)

<u>Ketumbaine</u>

Mawenzi-trachyandesite and -trachybasalt.

Andesite.

Mugearite-type.

Andesite.

Nepheline-andesite.

(Basic) - andesite.

8. <u>The Old Volcano Of Gelai</u>

Rare andesites with hornblende (JG091), basaltic and andesitic types with nepheline, (JG1103, JG1149, JG022), and Mawenzi-types (JG039) and (JG056) often with olivine, and at times associated with small subsidiary cones, were found around the base of the volcano of Gelai. In all, the plagioclase is generally near the andesine-labradorite border. These andesitic and basaltic types were collected well away from the area of concentrated cones and volcanoes in the SW, described later. It does seem reasonable to assume that they all belong to the earliest extrusive phase from Gelai proper. They do in fact correlate petrographically, with the period of maximum volcanic activity of Ketumbaine.

Nepheline mela-basalts certainly seem to be characteristic of the lower part of Gelai, at least on the western flank. Similar rocks were mapped near the Gelai magnesite deposits on the NW flank, on the lower northern flank, and up to 4,000 feet at least, on the southern side of the volcano. These rocks are remarkably rich in olivine, as are some of the rocks mentioned from Ketumbaine and the rift wall, but some specimens of the Gelai rocks contain large enclaves of a granular green olivine (J0908,909,946,900) which should prove a useful horizon when more detailed mapping of individual lava flows is undertaken. Olivine appears to be a common constituent in most of the variations of this nepheline-mela-basalt, except perhaps in the more andesitic types.

As noted on Ketumbaine, nepheline-melabasalt (J01310) overlie Mawenzi-type rocks at the south east side of the mountain, and can be seen between the heights of 4,000 and 4,5000 feet whilst ascending the motor track to the site of the native shop near the base of the eastern flank.

The nepheline-melabasalt is overlain in the same locality, by phonolitic-trachyte with barkevikite (J01308, J01309).

Ascending the westerly side of Gelai towards the crater, at about 5,000 feet a rock was collected which showed tendencies towards nepheline-melabasalt, being excessively rich in olivine. Just below 6,000 feet the younger phonolitic-trachyte was seen to overlie a rock more like nepheline-basanite (J0913). A specimen collected from near the summit 9,650 feet of the breached crater of Gelai, consists of a phonolitic-trachyte with barkevikite. Descending the westerly flank of the crater, similar specimens of phonolitic-trachyte were noted to just below 6,000 feet, where the junction referred to above was noted.

Two specimens of a variant of this phonolitic-trachyte were collected at the base of the W.S.W. flank of Gelai, adjacent to some of the large springs feeding the southern lagoon of Lake Natron. These rocks are interesting because of their large phenocrysts of anorthoclase. They do in fact resemble similar types of phonolitic-trachyte from the higher western flank of the mountain. The specimens (J3014, 916, 917) are some examples which contain anorthoclase and orthoclase phenocrysts, and these rocks are closely associated with the non-porphyritic phonolitic-trachytes, noted especially from near the summit of this volcano. The rock (J0085) from the base of the mountain, also one of phonolitic-trachytes, is a compact dark green rock, in the hand specimen, with phenocrysts of feldspar, and a much darker mineral; the rock shows a tendency to exhibit rudimentary foliation. Microscopically, it shows large crystals of anorthoclase, generally with irregular embayed outlines; and contains many fragments of pyroxene, opaque ore, possible sodalite, and a little calcareous material. The anorthoclase frequently shows very good fine-lamellar cross-hatched twinning. In some cases, around the periphery of the phenocrysts the mafic inclusions are concentrated, and zoning is common. Other phenocrysts of feldspar have the wide extinction angles of sodic plagioclase, and some feldspars are orthoclase with carlsbad twins. There are rare microphenocrysts of slightly pleochroic pale green pyroxene, also showing zoning. The extinction angle varies considerably, averaging about 52° $Z \wedge C$ with a maximum of 65°. The lower extinction angles were generally found in the smaller, deeper green, more sodic types in the ground mass. On one of the zoned microphenocrysts of pyroxene, the following optical properties were determined:-

	Inner zone	Outer zone
$Z \wedge C$	65°	60°
2V(+)	65½° - 67°	less than 65½° - by U-stage method

<u>Absorption</u>: X pale green, Y pale yellow green, Z pale grey green. X appears to be the direction of maximum absorption. These properties compare fairly well with aegirine-augite. The ground mass pyroxenes probably contain more of the aegirine "molecule". The ground mass is fine grained; a fair amount of small ore dust with fragmentary pyroxene gives it a general dark appearance. Abundant small laths of

feldspar, often exhibiting flow texture, and having an almost straight extinction angle, and low R.I. are oligoclase. Brown fragmentary barkevikite is also present. Some of the low double refracting interstitial matter is probably nepheline. There is at least one greatly altered olivine. Owing to its fragmentary nature, the properties of the amphibole are difficult to ascertain, but on larger pieces of amphibole (J01309), at times becoming very fragmentary, Z ∧ C was about 11° and the absorption Z>Y>X, with Z very dark brown, Y dark brown, X a lighter grey brown.

An analysis of JO 023 is given on Page 35 in Table No. 4 and shows total alkalis to be just over 10% and the normative feldspars are : Or 31.13, An 10.84 Ab 50.30 with 6.38 nepheline. A modal analysis was also attempted, and the results are given on p.35: the ground mass is really too fine grained for accurate modal work.

TABLE NO.4

Chemical analysis of phonolitic-trachyte with barkevikite
JG 023

SiO_2	57.34			
Al_2O_3	20.55	Corundum	.01	
Fe_2O_3	1.92	Orthoclase	21.15	
FeO	3.26	Albite	50.30	
MgO	.70	Anorthite	10.84	
CaO	2.23	Nepheline	6.53	
Na_2O	7.30			
K_2O	3.50			
H_2O +	1.50			88.41
H_2O -	.34	Olivine $2MgO.SiO_2$ $2FeO.SiO_2$	4.07	
TiO_2	.31			
P_2O_5	Tr	Magnetite	2.78	
MnO	.40	Ilmenite	.61	
CO_2	Tr			
				8.86
	99.72	water etc.		2.10
				99.77%

I.(1) 5.2.4. (Laurvikose)

Analyst: H.H.Herdsman.

Niggli Values: si 194.5; al 41.11; fm 19.02; c 7.036; alk 31.95; k .242; mg .2130; qz -33.3

Modal Composition. (Five traverses on one thin section)

	Average	Range
Pyrites	1.05	0.0 - 5.25
Anorthoclase	37.51	20.93 - 59.83
Apatite	.09	0.0 - .35
Aegirine-augite	6.83	.03 - 19.03
Barkevikite	10.83	4.7 - 20.11
Sphene	Nil	Nil
Calcite	.07	0.0 - .37
Sodalite (?)	7.25	Tr - 12.89
Ground mass feldspars	24.91	4.3 - 38.07
Decomposition material.	9.40	7.89 - 10.55
	100.05	

In the next Table No.5 the chemical analysis of JG023 is compared with six other similar rock types.

	JG023	Apachite	Rhomb-Porphyry (Norway)	Rhomb-Porphyry (Norway)	Kenyte	Phonolitic Trachyte	Rhomb-Porphyry Kibo
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
SiO_2	57.34	57.81	56.04	55.36	55.93	61.88	53.13
Al_2O_3	20.35	20.14	21.50	16.35	19.43	18.06	21.62
FeO	3.00	1.57	3.28	3.08	2.05	1.38	1.04
Fe_2O_3	1.92	3.55	1.00	5.29	4.30	2.19	3.46
TiO_2	.31	.54	.65	1.90	.57	.69	0.08
MnO	.40	.08	-	.18	.26	n.d	Tr
CaO	2.23	1.75	2.42	6.00	2.04	1.15	2.00
MgO	.78	.25	1.12	2.38	1.07	.61	1.10
K_2O	3.86	5.88	5.03	3.08	5.27	6.72	5.11
Na_2O	7.39	7.49	8,30	4.05	6.81	6.59	6.16
H_2O -	.54	1.23		.29	1.06		
H_2O +	1.56	.71	.67	1.46	.13	.37	2.36
CO_2	Tr	-	-	.20	-	-	-
P_2O_5	Tr	.46	n.d.	.94	.30	.07	0.40
ZrO_2	-	-	-	-	-	.08	.06
FeS_2	-	-	-	.11	-	-	-
SO_3	-	-	-	-	-	.05	.23
Cl	-	0.06	-	-	-	.30	-
BaO	-	-	-	-	-	.08	-
	99.72	100.24	100.16	100.25	99.96	100.52	99.96

(1) JG025. Anorthoclase - phonolite. Base of WSW flank of Gelai, by S.Lagoon of L. Natron. Analyst. W.H.Herdsman.

(2) Apachite ("amphibole-phonolite"). Huerto Camp, Apache Mountains West Texas. Heigen and Hechreiner, analysts: Central bl.f. Min 1925-A.

(3) Nepheline-rhombenporphyr. Vasvik tunnel, S.Norway. Forsberg, analyst. Brogger Syenitpegmatitgange, 38 and Eruptivgest. Krist. III, 160-64.

(4) Rhombenporphyry. Aslegard, Ringerike Str., Oslo, Norway. Dittrich, analyst. Brogger: Eruptivgest. Krist VII, 1933, 69.

(5) Kenyte, Mount Kenya, Prior analyst. Prior. Min. Mag. XIII 1903.

(6) Phonolitic trachyte. Bass Rock, Scotland. Day analyst. Trans. Edinburgh Geol. Soc. XII part 2. 1930.

(7) Nephelinrhombenporphyry. Nordostkibo about 5,500 metres (Kilimanjaro) Analyst L.Finckh in Rosenbusch Festschrift 1906.

The Apachite - "amphibole-phonolite" - where the predominant amphibole is intermediate between arfvedsonite and barkevikite - is remarkably similar to J6923. The main difference being in both the iron oxides and the value for potassium. This Gelai rock is comparable with rhomb-porphyries or similar types from Norway (3) (4), and Kenyte from Mt.Kenya (5) (6), and rhomb-porphyry from the Kibo peak of the Kilimanjaro massif. The Gelai rock contains more silica, and sometimes more alumina. It is least like the "rhomben-porphyry" from Aslogard, Oslo (4). Compared with the three other rhombporphyry types, total Fe is similar, but when FeO is high, Fe_2O_3 is low, and vice versa. Both K_2O and Na_2O are higher in all the rhombporphyries.

The Gelai phonolite has less silica than the phonolitic trachyte of the Bass Rock (8), more alumina, and the alkalis are rather lower. From the above it appears that the Gelai rock falls nearer the phonolites than the phonolitic-trachytes, but due to the presence of amphibole, not generally common in phonolites, it has the appearance of being a rather unusual phonolitic type.

On the SW flank of Gelai and further to the SW lie scores of parasitic cones trending approximately SW/NE from between Kerimasi and Oldonyo L'engai, towards the summit of Gelai. The whole effect is one of a lunar landscape, and these small cones obviously lie on a marked line of weakness. This has been shown on fig. 3 ., as probably expressing the northeasterly extension of the Eyasi rift valley. Although the parasitic craters and cones of this lunar landscape, high up the flank of Gelai, must from their position, be younger than the earlier nepheline-basaltic lava flows of the mountain on which they now rest, the same cannot be said of the other cones lower down the mountain and on the plains between Gelai and the rift wall. Little is known of the petrology of their lavas, but for the time being, these parasitic cones may be correlated with the nepheline-melabasalts of Gelai, which some of them certainly resemble.

From the broad outline above, it seems reasonable to state that the volcano of Gelai exhibits a magmatic trend along the following lines:-

Kibangaini (see below)

Trachyte
↑
Phonolitic Trachyte
Phonolite (Anorthoclase rich-type)
Nepheline-melabasalts
↑
Andesitic (including Nawensi) types

<u>Recapitulating</u>: It has been noted above that the Ketumbaine and Gelai volcanoes exhibit a similar kind of magmatic trend which overlap to some extent in time. The older Ketumbaine volcano, appeared to commence erupting with a basic andesite type of magma containing olivines and augites as porphyritic crystals; this type graded into prolific extrusions of the Nawensi trachybasalt and andesite types, with flow texture. Subsequently, small cones of nepheline-bearing rocks, with phonolitic and nephelinitic affinities, were extruded, and are considered to be equivalent to similar types noted at Gelai, if not even younger in age. Gelai, however, with some early andesitic indications, shows later fairly extensive nepheline-melabasalt lava flows, followed by more phonolitic types, and a fina considerable outburst of phonolite-trachyte, later tending to become more trachytic, and in this state may well be allied to the Kibangaini trachytes to the north. This combined magmatic trend can be summarized thus:-

```
Kibangaini—trachyte (riebeckite and arfvedsonite).
              ↑?
           trachyte (barkevikite)
           phonolitic-trachyte.
                     nephelinitic-phonolite.
Gelai      phonolite                                Lolgurdolgonja.
           nepheline-melabasalt
                     nepheline-andesite.
           ____________________________________
           Mawenzi-trachybasalt and -andesite.
              ↑
Ketumbaine andesitic-types
              ↑          mugearites, nepheline-andesites.
           (basic) andesite
```

During the Mawenzi trachy-basalt and -andesite stage, the undersaturated rocks, rich in olivines, were forming in part by crystal accumulation of the olivines in the magma basin. As the Mawenzi-type extrusive phase died out, so the olivine rich nepheline bearing lavas became the prominent extrusives. A time lapse between these two phases is indicated by their expression in major amounts in two different volcanoes. The nepheline, alkaline-richer types, when compared with the trachy-basalts, now undergo a further period of differentiation, culminating in the extrusion of the light magma fraction in the form of the trachytes of Gelai, and possibly Kibangaini.

The question of magmatic trend is considered in greater detail under the chapter on petrogenesis below.

C. The Kibangaini Trachytes

To the north of Gelai is a lowlying plateau which has suffered subsequent tectonic disturbance by gridfaulting. Amongst these small horsts and gräben lies the remains of an ancient lake called Kibangaini. Grid faulting continues southwards and affects the Gelai lavas to some extent around the base of the volcano, especially on the eastern side.

The Kibangaini trachytes are rather distinctive rocks in the field, and differ considerably from the more

andesitic varieties considered above, although they have much in common with some of the later Oolal extrusives. A typical specimen is JO1145 which macroscopically, is a fine grained rock, distinctly foliated, and showing some banding. The rock has an unusual mottled green grey appearance, typical of these trachytes; many small feldspars show reflection from cleavage faces. In thin section, this rock shows microphenocrysts of sanidine, situated in a very fine grained ground mass, consisting of abundant small laths of similar feldspar, all showing good trachytic texture, and embedded in a green and brown fragmentary ground mass. The deep green fragments are strongly pleochroic aegirine-augite, the larger pieces generally having a wider extinction angle. The brown and blue fragments are strongly pleochroic riebeckite. There is a little opaque ore present. Some of the sections of the larger feldspars normal to the c-axis show some inclusions around their perimeters, and most of the larger laths of sanidine have irregular cross-fractures.
The analysis of this rock is quoted below in Table No.6 -

<u>Chemical analysis of Kibangaini riebeckite-trachyte JO1145</u>

		NORM.			
SiO_2	62.30	Quartz		7.50	
Al_2O_3	14.00	Orthoclase		28.91	
Fe_2O_3	6.26	Albite		44.54	
FeO	1.77				80.95
MgO	0.51	Acmite		7.39	
CaO	1.93	Diopside $MgOSiO_2$	1.30		
Na_2O	6.23	$CaOSiO_2$	1.51	2.81	
K_2O	4.93	Wollastonite		.58	
H_2O +	.38	Magnetite		3.94	
H_2O -	.17	Haematite		.96	
TiO_2	.78	Ilmenite		1.52	
P_2O_5	.67	Apatite		1.00	
MnO	.15				18.80
				H_2O	.55
	100.10				100.20

Analyst: C.V.Green B.Sc., A.R.I.C. II.(1) 5.1.3. (Ilmenose)

Niggli values: si 234.7; al 30.03; fm 20.64; c 7.998;
alk 34.55; mg .1102; k .3305; qz 7.41

From the above it is readily seen that some normative quartz is present, while the normative feldspars are

Or 28.01, Ab 44.54: 7.39 of normative acmite represents the highest femic mineral present.

In these Kibangaini trachytes, the common amphibole appears to be riebeckite. In JG 1066 some barkevikite was also noted, and may represent a transitional type to the Golai barkevikite phonolitic-trachytes. In nearly all slices the amphibole is very fragmentary, but in JG1130 it was slightly easier to identify. The extinction angle $X \wedge C$ is about 8^{o}, absorption $X > Y > Z$, with very distinctive pleochroism; X dark blue-green, Y dark brown, Z lighter yellow-brown.

A specimen JG1147 from the most easterly point reached on the Kibangaini plateau, which rises eastwards away from Lake Natron, is rather different from the other Kibangaini specimens, as the amphibole associated with the aegirine-diopside appears to be mostly kataphorite, and this rock is therefore strictly a kataphorite-trachyte.

The kataphorite extinction angle varies considerably, $Z \wedge C$ $31-47^{o}$ no dark blue-green colour of the riebeckite was noted, and the maximum absorption was no longer along the elongation, but along the Y direction, parallel to the b-axis. Y is dark brown, Z and X lighter, more purple brown in colour, and very nearly of the same colour intensity.

By way of a slight digression, it is interesting to compare analyses of the barkevikite phonolitic-trachyte JG323 of Golai, the Kibangaini riebeckite trachyte JG1145, and a kataphorite trachyte from just over the Kenya border in this area, with analyses for barkevikite, riebeckite and kataphorite respectively.

TABLE NO. 7

	JG1145	Riebeckite		JG923	Barkevikite		Kataphorite		Kataphorite Trachytes		
	1	2	3	4	5	6	7	8	9	10	11
SiO_2	62.39	49.68	50.01	57.34	42.46	42.27	45.53	49.10	60.74	61.20	61.96
Al_2O_3	14.00	1.34	-	20.55	11.45	6.31	4.10	5.50	15.58	14.36	13.12
Fe_2O_3	6.26	17.66	28.30	1.92	6.18	6.62	9.35	4.20	3.66	4.31	5.30
FeO	1.77	19.55	9.87	3.06	19.93	21.72	23.72	27.70	3.55	4.09	3.56
MgO	0.51	-	0.34	.78	1.11	3.62	2.46	0.17	0.38	0.77	0.56
CaO	1.98	3.16	1.32	2.23	10.24	9.68	4.89	0.13	0.97	2.54	2.54
Na_2O	6.23	7.61	8.79	7.39	6.08	3.14	6.07	10.50	6.59	5.46	-
K_2O	4.93	-	0.72	3.58	1.44	2.65	0.88	1.60	4.62	4.72	-
H_2O +	0.38	1.67 (H_2O ±)	-	1.56	-	0.40 (H_2O ±)	-	-	1.20	1.18	-
H_2O -	0.17		-	.54	-		-	-	1.21	0.60	-
TiO_2	.75	-	-	.31	In SiO_2	1.01	2.96	-	1.05	0.35	0.86
P_2O_5	.67	-	-	Tr	-	-	-	-	0.07	0.09	0.09
MnO	.15	-	0.63	.46	0.75	1.13	-	0.50	0.26	0.17	0.17
	100.19	100.64	99.98	99.72	99.64	98.63	99.96	99.40	100.18	99.84	-

1. JG1145 Riebeckite-trachyte, Kibangaini: Analyst C.V.Green B.Sc., A.R.I.C. Colonial Geological Surveys, Mineral Resources Division, London.
2. Riebeckite. Rock Minerals. Iddings. P.353 No.57.
3. " " " " " No.58.
4. JG923 Anorthoclase-barkevikite-phonolite. Analyst. W.H.Herdsman.
5. Barkevikite. Rock Minerals. Iddings. P.353 No.51.
6. " " " " " No.52.
7. Kataphorite " " " " No.53.
8. " " " " " No.54.
9. Kataphorite-trachyte. East of Lake Naivasha. M.H.Hey Analyst.(1)
10. " " glassy. West shore of Lake Magadi Analyst.(1) W.H.Herdsman.
11. Partial analysis of another sample of 10 by G.T.Prior(1)

(1) W.Campbell Smith. Q.J.G.S. Vol. lxxxvii, 1931, p.227. "On rhyolites etc. from Kenya Colony".

It is readily seen that the chief chemical differences between the trachytic rock types from Golal and Kibangaini, are to a great extent, a function of their amphibole content.

The riebeckite-trachyte is higher in silica and ferric iron because riebeckite is similarly higher. On the other hand, it is noticeably lower in alumina than the barkevikite-trachyte, and to a less extent, lower in ferrous iron and lime, because barkevikite is richer in both of these than riebeckite. This of course is seen readily be a comparison of their chemical formula:- (1)

Riebeckite $H_2Na_2Fe''_3Fe'''_2\ Si_8O_{24}$

Hornblende $H_2NaCa_2(MgFe)_4Al_3Si_6O_{24}$

Barkevikite is similar to hornblende but richer in Fe" and alkalis.

Arfvedsonite $H_2Na_3Fe''_4Fe'''\ Si_8O_{24}$

Kataphorite belongs to a series between arfvedsonite and barkevikite. Therefore, applying the same principle, an analysis of kataphorite-trachyte should indicate more CaO and Al_2O_3 and less SiO_2 than the riebeckite-trachyte, due to the partial influence of the hornblende "molecule" of the kataphorite. Analyses (10) and (11) in the table are both from a glassy kataphorite-trachyte from the west shore of Lake Magadi; less than 30 miles north of Kibangaini and slightly west of the JG1147 locality. Analysis (9) is from the Lake Naivasha region, less than 150 miles due north from Lake Magadi.

Apart from the Al_2O_3 in the partial analysis of the rock from Magadi, which shows lower Al_2O_3 compared with the riebeckite-trachyte, although kataphorite contains more alumina than riebeckite, the analyses do show the suspected variations due to the kataphorite. With the Naivasha example the CaO is less than that of the riebeckite rocks. The position of the alkalis and iron, can be so variable in kataphorite, dependent on the predominant barkevikite or

(1) Winchell A.N. Elements of Optical Mineralogy. 3rd Ed. p.237.

arfvedsonite "molecule", that it is impossible to state at the moment, without more available optical and chemical information, whether in this case the iron and alkalis should be greater or less than riebeckite. As a check it can be seen that the CaO and Al_2O_3 should be less, and the SiO_2 more in the kataphorite-trachyte than in the barkevikite-trachyte. This agrees for all but the CaO determinations in the quoted Magadi glassy kataphorite-trachyte.

From the field reconnaissance work the age relationships of the above can only be given tentatively. Probably the barkevikite bearing rocks are the older, followed by the riebeckite-trachytes with kataphorite-trachytes possibly the youngest. Nowhere has this actually been demonstrated. In a gorge section at the SE end of Kibangaini trachytes were seen to overlie a more basaltic rock (JG1149) showing both nepheline-basanite and Mawenzi-type tendencies. The basaltic rock resembles similar types found around the west and north base of Gelai (JG1162, 982). This gorge section only shows the Kibangaini trachytes are older than the basal rocks of Gelai. A more detailed study in this area, combined with an investigation of the similar Kenya lavas would prove most interesting.

To conclude this section it can only be stated regarding the mode of origin of the Kibangaini trachytes, situated as they are on the Kenya border, and with no knowledge of what happens over the border; that they are possibly plateau lavas of fissure eruption. In the Kibangaini area their expanse is small, but it should be obvious from the analyses quoted that there may well be a belt of amphibole-trachytes, trending northwards, and lying to the east of the main western escarpment. Magmatically they could be linked with the waning stages of Gelai's barkevikite-trachytes, and if so, represent the most siliceous and alkaline type reached by the parent magma of the older lavas in the area under consideration.

This point is taken up later in the petrogenesis section.

General Conclusion

The combined evidence from the Kotumbaine and Gelai volcanoes is indicative of a magmatic trend from mafic-rich andesite to trachytic types as shown above; also it has been suggested that Oldonyo Sambu is possibly contemporaneous with Kotumbaine.

Turning to the evidence provided by the rift wall consisting of lava flows from volcanoes situated outside the area considered here in some detail, it has been shown in one place that the nepheline-melabasalt (JG011) overlies a more andesitic type with nepheline (JG010); a state of affairs noted in the Gelai and Kotumbaine sequence. Secondly, magma of an apparently younger, more phonolitic, even nephelinitic stage, appears to have welled up the fault scarp, fissure fashion, and formed numerous small cones along the base of the scarp. This later phonolitic tendency is also consistent with the Gelai and Kotumbaine trend. Thirdly, there is the undisputable evidence that the Kerimasi calcareous and alkaline extrusives are younger than the older extrusives of the rift wall.

The table/No.8 indicates the specimen numbers of older lava rocks from which thin sections have been made, arranged in rock types, and enables a more ready appreciation of correlation petrographically of the different areas.

Looking wider afield in Tanganyika only, for the time being, it is interesting to note the Mawenzi-type of the rift wall, Kotumbaine, Gelai and Oldonyo Sambu is named after the Mawenzi peak of the Kilimanjaro massif where it occurs abundantly; and similarly, the anorthoclase-rich rocks of Gelai and perhaps Oldonyo Sambu, resemble the rhomb-porphyries collected from Kibo, the highest volcano on Kilimanjaro.

It is fully agreed that a more detailed petrographic study of this very interesting suite of rocks will emphasise the obvious similarity in very many cases, of these and the

Kenya volcanics of similar nature, described by W.Campbell Smith[1] and would in fact, stress the likeness with other Central and East African localities and Mozambique[2]. No attempt has been made to use Campbell Smith's nomenclature at this stage, as it is the magmatic trend rather than a purely detailed petrographic account of these rocks, which form the relevant part of this account.

(1) Smith W.Campbell 1931. A classification of some rhyolites etc. from Kenya Colony. Q.J.G.S. Vol. LXXXVII, p.212.

(2) Holmes A. 1916. The Tertiary volcanic rocks of the district of Mozambique. Q.J.G.S. Vol. LXXII, p.222.

ROCK TYPE TABLE NO. 8 CLASSIFICATION TABLE OF THE OLDER [illegible]

Localities	Andesite	Augite-porphyry Andesite-type	Trachytic types andesite-basalt	olivine-rich andesitic types	Andesite aff basanite	Kerimasi-type trachy-andesite-basalt		Nepheline-andesite	Nepheline-melabasalt	Nepheline-tephrite	Phonolite (aff. nephelinite)	Phonolitic trachyte
						olivines common						
Rift Wall S. of Kerimasi Lagaruka Area.	787 783(2)	776 777	773 783(1) 763				778 779 788 760(1) 760(2)		785 768		767 770	
Rift Wall Kerimasi-L'engai-Mosonik Area.		953			910(1) 910(2)(stained)			832 877	844 840 880 870 878 911 971		812(1) 812(2) 843(1)(2)(3) 861 854(1)(2)	
Rift Wall Kenya Border to Mosonik Old Sambu		1120 1095(b) 1095(c)	1003	991 1114 1088 1093(1)(2)	1090 1112 1132	1093(3) 1117 1115 1170 1103 1089(1)(2)(3)(4)	1092(1)(2)(3)(4) 1100 1111(a)(b)(c) 1096(a)(b)(c)(d)	975 1095 990 977		992 976		
Golai	901		856		1102(1)(2) 923 1156 1149		859 (1511)?		899 898 (stained) 898 1310 921 900 945		923 924	914(1)(2) 915 916 917 918 919 920 1308 1309 902
Ketumbaine	1304 1300 804 1306	1307	1290 1305 1317 1295 1303 1301	1290	802(1)(2) 806(1)(2)	805(2)	1298(1)(2) 795(1)(2)(3) 805(1) 1292 1294(1)(2) 1297(1)(2) 1301(1)(2) 1305 1291	801 791 1315 1316	793 797		800(1) 800(2) 799 1289 1314	

The Younger Extrusives

Kerimasi

1. Previous Geological Work

Observations made on two short reconnaissance visits to this extinct volcano in 1930 and 1931 enabled a provisional geological map to be compiled from compass and wheel traverses, utilizing existing German trig. points, and this is incorporated in fig. 1 . Petrologically, the volcano of Kerimasi consists essentially of ejectamenta, of a calcareous and alkaline nature. These ejectamenta vary in size from large blocks located in volcanic breccia down to fine ash.

In 1907 Uhlig[1] noted of Kerimasi that (translated), "its ejectamenta unite it southwards to the rift wall in the form of an anticlinal arch. At its foot, south-west to north we were chiefly able to establish coarser and finer partly very hard tuffs. It appears to us also that lavas had flowed out to the west".

Rosenbusch[2] described a normal shonkinite, in a tuff from the east of Kerimasi, containing diopside with aegirine-augite mantles, nepheline, sanidine, perovskite, and sphene. An analysis of one of Uhlig's rocks was mentioned by Finckh[3] in 1912 as an "ijolite", and in 1921 by Brogger[4] who on the basis of Wyns's analysis in Finckh's work suggests the minerals could be represented chemically thus:-

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(1) Uhlig C. 1907 Die sogenannte Grosse Ost. Afrika. Geogr. Z. Vol. 13.

(2) Rosenbusch H. 1908. Mikroskopische Physiographie etc. p.1437.

(3) Finckh L. 1912 Deuts. Zent. Afrika. Exp. 1907-1908 p.44.

(4) Brogger W.C. 1921. Die Eruptivgesteine Des Kristianiagebeites (IV).

TABLE NO. 9

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	P_2O_5	F	Total
Nepheline	19.52	-	15.49	-	-	-	0.20	7.22	2.99	.5	-	-	45.72
Pyroxene	16.05	-	0.04	0.38	2.46	3.62	7.34	.15	.04	-	-	-	30.08
Melanite	4.15	1.20	0.22	3.00	-	-	4.26	-	-	-	-	-	12.83
Titanite	0.27	0.37	-	-	-	-	0.26	-	-	-	-	-	0.90
Apatite	-	-	-	-	-	-	4.19	-	-	-	3.38	.29	7.76
Magnetite	-	-	-	1.50	0.68	-	-	-	-	-	-	-	2.18
O (?Perovskite)	-	0.09	-	-	-	-	0.12	-	-	-	-	-	0.21
Rest	-	-	-	-	-	-	0.23	.13	-	.64	-	-	1.00
	39.99	1.66	15.75	4.88	3.14	3.62	16.60	7.5	3.03	.94	3.28	.29	100.68
Eyme's analyses	39.26	1.66	15.75	4.83	3.14	3.62	16.60	7.5	3.03	.94	(3.28)	.29	99.66

Eyme's original analysis as quoted in Finckh does show 0.20% P_2O_5 although Brogger omitted this figure, no doubt, in error. From the above, Brogger adjusted to percentages, the nepheline, pyroxene, and melanite thus:-

TABLE NO. 10

	Nepheline	Pyroxene	Melanite
SiO_2	42.70	53.36	32.35
TiO_2	-	-	4.53
Ti_2O_3	-	-	4.83
Al_2O_3	33.88	0.13	1.71
Fe_2O_3	-	1.26	23.30
FeO and MnO	-	8.18	-
MgO	-	12.04	-
CaO	0.44	24.60	33.20
Na_2O	18.80	0.50	-
K_2O	0.33	0.13	-
H_2O	0.08	-	-
	100.00	100.00	100.00

Brogger (1921) then states that this rock is strictly a melanite-melteigite, and under the same heading, Johannsen[1] refers to it, noting:- "The rock occurs as inclusions in nephelinites and shows irregular grains of melanite, abundant green aegirite diopside (c:C 60° to 70°), pleochroic in green and yellow-green colours, abundant large grains of titanite, corroded prisms of apatite, and interstitial nepheline. Johannsen also omits Eyme's P_2O_5 figure, although the quoted modal analysis is correct.

In 1935 Erdmannsdorffer[2] persisted in calling the rock and ijolite, and also mentioned syenites and nepheline-syenites from Kerimasi and Oldonyo L'Engai.

In the same work by Brogger (p.240) referred to above, he compares melteigites and "kalkstein", from Kerimasi, with similar rocks from the Fen district, likening the latter to sövite.

Representatives of most of the above mentioned rocks were collected by the writer in 1930 and 1931 who was un-aware of

(1) Johannsen A. 1938. A descriptive petrography etc. vol.IV. p. 331.
(2) Erdmannsdorffer O.H.1935. Über Wollastoniturtit und die Entstehungsweisen von Alkaligesteinen. Sitzungsberichte der Heidelberger Akademie der Wissenschaften. Mathe Kl. 1935.

any previous petrological work, until returning to Britain, where the above publications are available.

8. The Carbonatites of Kerimasi

The economic importance of carbonatite occurrences for minerals other than the main constituents of some of their rocks, e.g. limestone in the case of sövite, and at times iron ore from jacupirangite, has been outlined by K.A. Davies[1], N.J. Guest[2] and more recently by T. Deans[3] of the Colonial Geological Surveys, Mineral Resources Division, London. Close co-operation has been maintained with Deans, who, as a specialist on carbonatites has identified, or had identified, many of the rarer minerals in the Kerimasi rocks. Work is continuing on the Kerimasi rocks, both in the field and in the laboratory.

The calcareous, carbonatite or sövite rock types which have been collected from the Kerimasi agglomerates and tuffs, have been subdivided into five different varities, considered in some detail below:-

(1) Carbonatite, with forsterite, magnetite and some apatite.
(2) Carbonatite, granular type.
(3) Carbonatite, cellular-type.
(4) Carbonatite, with apatite.
(5) Carbonatite, calcite-rich.

Nowhere was carbonatite actually found outcropping, but it is believed it may well occur high up the eastern flank of the mountain, as all the carbonatite specimens here described, were collected from the lower eastern slopes. Two attempts were made to reach the summit - 7,540 feet. One attempt from the south was unsuccessful owing to low clouds completely encompassing the party at about 6,000 feet; the grass and bush

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(1) Davies K.A. The phosphate deposits of Eastern Province, Uganda. Econ. Geol. Vol. 42 pp. 137-160.
(2) Guest N.J. Notes on the present day economic importance of carbonatites etc. Memo. Geol. Survey of Tanganyika June, 1952.
(3) Deans T. Recent discoveries of Columbium in Africa. Col. Geol. Min. Res. Vol.3. No.1.

vegetation was thick here, but no outcrops were exposed except calcrete, under the brown soil. The successful ascent was made on a ridge on the north-east flank, where similar calcrete and brown soil were noted, but no outcropping rock. The summit and unbreached crater are covered with rich tall grass and bushes, but little evergreen forest was evident. Any outcropping rock here other than calcrete, will probably only be found by pitting.

(1) <u>Carbonatite, with forsterite, magnetite and some apatite</u>

The specimen numbered JG010 from the extreme SSE flank of Kerimasi, is typical of this type of carbonatite, and in the hand specimen is seen to be a dark grey, compact, medium grained rock, with cleavage faces of calcite showing a slight parallelism. The rock is not excessively heavy, although its rather dark colour is due to a fair amount of magnetite.

In thin section, besides the abundant, large, interlocking, calcite crystals, there is much black magnetite with a peculiar ragged outline, together with colourless, generally anhedral olivines. Intimately associated with the magnetite are small pale green grains, probably spinel, often with a core of magnetite and at times showing good octhedral form. A little apatite is also present, and there are some small anhedral areas of reddish-brown material generally associated with the magnetite.

Deans identified the olivines in a residue, as forsterite or possibly monticellite, and some fluorite was present. Further digestion with HF and HCl left a minute concentrate of about 0.01%, of the original rock, which he thought consisted of baddeleyite (ZrO_2). Subsequently verification of both the forsterite and baddeleyite was made by X-rays by Dr.C.F.Claringbull of the British Museum. Deans in a personal communication is of the opinion that baddeleyite is quite definitely a mineral of carbonatites and ejected blocks of alkaline volcanoes, whereas the other minerals can occur in both carbonatites and contact marbles, a point taken up later, more fully, under petrogenesis.

TABLE NO. 11

Chemical analysis of Carbonatite, with forsterite, magnetite and some apatite

JG010			1.
SiO_2	5.83	SiO_2	(2)0.05
Al_2O_3	0.70	Al_2O_3	-
Fe_2O_3	11.36	Fe_2O_3	-
FeO	1.08	FeO	(1)3.44
MgO	11.70	MgO	15.83
CaO	35.01	CaO	31.30
Na_2O	0.13	Na_2O	-
K_2O	0.00	K_2O	-
H_2O +	0.40	H_2O +	-
H_2O -	0.03	H_2O -	-
TiO_2	0.30	TiO_2	-
P_2O_5	1.14	P_2O_5	0.43
MnO	0.38	MnO	0.02
CO_2	28.30	CO_2	43.61
	99.93		100.37

(1) Total Fe expressed as FeO
(2) Residue insoluble in HCl

1. Napak carbonatite, Uganda, Analyst D.C.King.

JG010 Analyst R.O.Roberts, M.Sc., A.R.I.C.

NORM of JG010		
Corundum	.08	
		.08
Na_2CaSiO_4	.24	
Forsterite	12.10	
Akermanite	1.01	
Magnetite	5.10	
Haematite	7.84	
Ilmenite	.61	
Excess MgO	4.76	
Apatite	2.69	
Calcite	64.39	
		98.75
H_2O		.43
		100.03

Normative Compositions 1	
Calcium carbonate	54.89
Magnesium carbonate	33.03
Ferrous carbonate	5.80
Apatite	1.01
Iron oxides, Silica etc.	5.74
	100.37

Niggli values:- si 8.375; al .614; fm 40.01; c 59.10; alk .74; k 0.0; mg .716; qz 92.50.

Owing to the very low silica content in the chemical analysis of JG010, it has been necessary to show in the norm alumina as corundum, and excess MgO under femics; otherwise the norm brings out the essential minerals of the rock quite satisfactorally, the MgO being largely accounted for by the forsterite. An analysis of a similar carbonatite from Napak is quoted for comparison purposes.

(2) Carbonatite, granular-type

The second carbonatite type is similar to the above, but consists mainly of smaller grains in a granular texture. The specimen JG1830 from a gorge on the S. flank is an example and under the microscope consists almost entirely of calcite. Under high power there is a little apatite present, and some brown limonitic staining and possible siderite. Another specimen, JG1870 from a ridge on Kerimasi, about 3 miles W. of Kisetey hill, contains more magnetite, at times associated with a brown, massive, anhedral mineral, which resembles melanite garnet seen in some of the other sections. If olivine is present it occurs in exceedingly small grains embedded in the calcite. Another granular type similar to the above, but containing considerably more brown limonitic dust, is JG1247. It can be considered as gradational to the next division and was collected on a ridge on the SE side of Kerimasi, near the point where Kerimasi starts to rise steeply towards the summit.

(3) Carbonatite, cellular type

Macroscopically, this series consists of very distinctive, well weathered rocks exhibiting cellular structure. The rocks are grey in colour, very open-textured and with numerous cavities. The hand specimens of JG822 and JG823, both from the base of the SE flank show this particular honeycomb structure effectively. The cavities, not continuous, are aligned in large-scale lineation, and probably have been formed by selective erosion, as under the microscope some banding was noticed. Macroscopically, some of the other carbonatite specimens also show unmistakable banding, (e.g. JG830).

Microscopically, JG822 consists mostly of granular calcite, often showing a distinct but not continuous banding. Opaque ore is rare, but limonitic dust is common. In a more weathered limonitic-rich portion of the slide, there are fragments of aegirine-augite, colourless clinopyroxene, melanite garnet and possible pyrochlore. Other examples, showing similar characteristics and minerals, are, JO1253 and some samples of JO1247, at times the brown melanite garnet contains cores of magnetite. These three specimens were collected on the SE side of Korimasi, and are commonly associated with areas of surface calcrete, a compact, hard, secondary limestone.

(d) Carbonatite with apatite

Rocks in this group contain more apatite than in the other carbonatites.

The hand specimen of JG814 from the base of the easterly flank is similar to JG810, of the first group; it is compact, fine grained, with rudimentary foliation, generally dark in colour, but with whiter patches. Some small veins of calcite cut across the foliation. Under the microscope, the rock is seen to consist mainly of anhedral, elongated and aligned interlocking calcite grains, and much anhedral magnetite in small fine grained areas associated with light green coloured spinel dark brown melanite, and apatite. The larger of the brown garnets are at times euhedral, showing the hexagonal outlines of the dodecahedral form, and have an R.I. higher than the spinel. In some cases the faintly coloured spinel has a core of magnetite, and is also surrounded by a strong border of magnetite. Forsterite is present but only in minor quantity.

Another rock in this division of apatite-bearing carbonatites is JG828 from the lower north easterly flank which showed on chemical analysis only 3.34% P_2O_5 representing 7.73% of normative apatite - Uhlig's melanite-melteigite rock, analysed by Eyme see Table No. 9 showed a comparable 7.70% of normative apatite.

In the hand specimen JG828 has very distinct colour banding and is more coarsely crystalline than most other carbonatite types. The darker bands are the more ferruginous material, and the lighter bands the purer calcite. The weathered surface is buff coloured and in thin section is seen to consist of very fine grained limonitic and calcitic clay material, incorporating small fragments of most of the other minerals identified in J0014 and mentioned above. Calcite occurs in relatively large anhedral interlocking crystals, often enclosing prisms of apatite; also present are large areas of brown to opaque material, showing under reflected light a dark brown colour and are associated with a little leucoxene, they are probably the remains of very altered melanite: the six-sided garnet outline is still preserved in some cases. Also present are smaller unaltered magnetite grains, at times surrounded by a faintly pleochroic pale brown biotite, some flakes of which are considerably distorted. Olivine is present and both baddeleyite and forsterite were found by Deans to be more abundant in the residue of this rock compared with J0010.

TABLE NO. 12

Chemical analysis of Carbonatite with apatite JG020

	JG020		1.	2.
SiO_2	1.52	SiO_2	0.20 (1)	1.01
Al_2O_3	.35	Al_2O_3	-	0.23
Fe_2O_3	3.24	Fe_2O_3	-	0.64
FeO	1.13	FeO	4.17 (2)	3.19
MgO	1.15	MgO	2.38	0.83
CaO	51.00	CaO	50.82	40.03
Na_2O	Tr	Na_2O	-	.14
K_2O	Tr	K_2O	-	.13
H_2O +	1.12	H_2O +	-	.26
H_2O -	.27	H_2O -	-	.14
TiO_2	.15	TiO_2	-	0.00
P_2O_5	3.34	P_2O_5	1.39	.09
MnO	.02	MnO	0.16	1.12
CO_2	35.26	CO_2	40.92	41.00
	99.81		100.06	
			BaO	0.60
			SrO	.009 (3)
			F	.10
			S	.49
				100.44
			Less O=S.F=	.33
				100.11

(1) Residue insoluble in HCl
(2) Total Fe expressed as FeO
(3) Determined spectroscopically by S.Landergren.

JG020 Analyst N.H.Herdsman.

1. Napak carbonatite, Uganda, analyst B.C.King.
2. Alvikite Dyke. Alnö, analyst. H.Dlix.

JG020 NORM.

Corundum	.41	.41
Forsterite	.83	
Calciumortho-silicate	3.07	
Magnetite	4.64	
Ilmenite	.30	
Excess FeO	.73	
MgO	.96	
Apatite	7.73	
Calcite	80.20	
		98.77
H_2O		1.30
		100.07

Normative Composition 1.

Calcium carbonate	87,66
Magnesium carbon-ate	4.55
Apatite	3.20
Iron oxides, Silica etc.	4.77

NORM of 2

or	0.70
ab	0.83
CO_2	0.04
Total sal	2.07
ac	0.47
mt	0.70
il	0.13
ap	1.71
fr	0.20
pr	1.07
cc	88.23
mgt	1.05
sdt	3.71
rct	1.03
Total fem	97.98
H_2O	0.40
	100.45

Niggli Values: si 2.426; al .300; fm 40.01;
JG020 c 59.64; alk 0.00; K 0.00;
mg .2016; qz - 97.375

The rock JG823 consists almost essentially of calcium carbonate; the very low silica content necessitated the alumina being shown in the norm as corundum, and the excess FeO and MgO, as femic material. Most of the iron appears to be in magnetite, which if need be, could easily be separated from the calcite and apatite. Two similar analyses of carbonatites from Napak and Alno are quoted for comparison purposes.

Relatively abundant baddeleyite was found by Deans in residues of JG851 from the lower NW flank. In the hand specimen this rock is white or gray, with small specks of dark ore and mica. The rock is massive, with a saccharoidal appearance. In thin section, besides abundant calcite, magnetite is present, associated with faintly pleochroic biotite as previously noted in JG823, and much apatite in pockets. Dark coloured garnet is rare, and there are patches of leucoxene-like material associated with some of the ore and biotite.

Grading into the previous section is JG1234 from the lower S. flank but is much less cellular in texture. In thin section it contains one large fragmentary melanite, orange brown in colour with a darker brown outer border, and is associated with euhedral magnetite. Very small melanites occur with magnetite in a fine grained granular matrix of calcite. There are some pale yellow coloured perovskite grains, with very weak birefringence. Apatite is relatively rare.

Another specimen JG1264 from above the small ridge to the SW of Kerimasi, is a dark carbonatite in the hand specimen. In thin section it is characteristic of this variety of carbonatites, but contains a good deal of magnetite and olivine surrounded by a dark border of limonitic-looking material under reflected light. Pale green spinels with magnetite cores are present as small grains while very rare, small, isotropic, pale yellow grains possibly octahedral and with a high R.I. may be pyrochlore.

In the thin section of another specimen J01267 from a dry water course on the E. flank of Korimasi and W. of Kisotoy hill, the veins carrying apatite and magnetite are well displayed. In all the above rocks in this group, apatite is generally very abundant in small pockets and veins, seen under the microscope. Any similar large scale development, in dykes of apatite-rich carbonatite, would be interesting economically from a phosphate point of view.

(5) Carbonatite, calcite-rich

The last division of the carbonatites consists of almost pure calcite rocks. The hand specimens of J01266, 1269 and J01271 all from dry river sections on the east side of Korimasi and west of Kisotoy Hill are similar, and consist of white calcite crystals with small darker patches of ore and other mafic minerals; the rocks are medium grained. Microscopically J01265 found to the south of the above specimens, consists of large calcite plates, often showing twinning, and smaller areas of more granular calcite. Also present are patches of apatite, associated with magnetite, and a little decomposed olivine.

Under the microscope J01266 consists of predominant large plates of calcite, which are veined by more granular calcite with ferruginous decomposition material, ore, apatite, aegirine-augite, and olivine; fragments of all these minerals often form the centre of oolith - like formations. There is present at least one possible pyrochlore crystal.

3. The Tuffs of Korimasi

The tuffs and cementing material, in which larger blocks of a great variety of rock types are found, are now described petrographically. Four somewhat different types of tuff have been recognised:-

(1) Calcareous tuff.

(2) Calcareous tuff with ferruginous material.

(3) Calcareous tuff rich in aegirine and nepheline.

(4) Calcareous tuff rich in mafic minerals.

These are considered below in some detail:-

A good slide typical of the first division of the more calcareous tuffs, is JG314 (1) from the foot of a small scarp at the base of the eastern side of Kerimasi, which shows the weathered and less weathered rock. Microscopically, the less weathered portion consists of both angular and granular calcite fragments, less common magnetite, green to yellow aegirine-augite, apatite, ferruginous dust, and possibly yellow pyrochlore. Olivine, sphene, brown garnet, and faintly coloured biotite are also present, and are all embedded in a fine grained granular cement of calcite. The more weathered portion, is banded and is yellow to orange in colour showing under reflected light, grey clay-like materials. Both larger and smaller fragments of similar minerals to those already mentioned are present, together with larger rock fragments. Aegirine-augite is particularly common, also brown very pleochroic hornblende is present, and small yellow, high relief, octahedra which may be pyrochlore. One of the larger rock fragments consists mainly of clinopyroxene and melanite garnet.

A thin section of JG321 from the lower south-east corner of Kerimasi, is very similar to the unweathered portion of the above. It contains large green to brown coloured pyroxene, a relatively large fragment of perovskite, showing twinning and low birefringence under crossed nicols, and a little, ore, biotite, and apatite embedded in a calcareous cement with some limonitic dust. Macroscopically, JG321 consists of a dark grey, fine grained, matrix, in which are embedded all sizes and shapes of the different minerals mentioned above, and possibly others so far undescribed.

A thin section of JG320(3) from a dry water course at the base of Kerimasi, and 93 from Kisetey is similar. Larger apatites are present, some orthoclase and octahedra of perovskite; while small clusters of yellow octahedra which may be pyrochlore are often found near the magnetite grains: aegirine-augite is also present. There are large nearly isotropic anhedral areas which may be analcime and often contain many inclusions. Some zeolite was also noted.

Macroscopically, JG826 is a very fine grained tuff in contrast to JG821, which is a hard, compact, fine grained tuff; small fragments of the more common minerals mentioned above can be seen with the aid of a hand lens. From the same locality as JG826, but underlying it, another similar specimen JG823 (2) was collected. In these particular slides the tendency to develop oolith-like structures is exhibited. Commonly aegirine-augite forms the core of these pseudo-ooliths, and such structures are seen in other specimens. Rock lapilli are also present, but the cement remains predominantly calcite.

(2) Calcareous tuff with ferruginous material

Although the rock JG826 was described in the preceeding section, one slide of this rock, JG826(1) is included in this category, as it contains a fair amount of magnetite and ferruginous powder, seen outlining heavily the more isotropic areas of possible analcime. The matrix is still mostly calcite.

The thin section of JG793(2) is similar but contains larger areas of dark brown cloudy material, with some magnetite, and many small laths of altered wollastonite. Under reflected light yellow limonite can be seen commonly surrounding the ooliths, which are cemented together by calcite, although a little zeolite is also present interstitially. This rock was collected from a small hill called Mamota, near to the old track leading to Gelai, and Lake Natron, and some way south of Kerimasi. Another slide JG793(4) of the same rock shows more abundant zeolite often occurring between the oolith-like areas and the calcite cement.

A slice of JG1269 collected from where the motor track climbs the small escarpment to the south-east of Kerimasi, contains much dark ferruginous fine-grained clay. "Oolith" formations as noted above are still present, but less distinct. Small remains of aegirine-augite are present, and one large calcite plate is considerably decomposed. The macrospecimen of JG1250 is a fine grained, purple coloured tuff, with small darker coloured aggregates, commonly biotite. It will be noticed that the difference in the colour of these tuffs has been utilized on the sketch map fig. 1 ., in separating in the field one otherwise similar kind of tuff from another.

From the top of the scarp some 1½ miles north of JG1250 another fine grained tuff was located, it is light brown in colour, and numbered JG1253. Macroscopically, ore, pyroxene, nepheline, and secondary limestone are to be seen infilling some of the cavities on the pitted surface. In thin section the matrix is rich in iron and minerals similar to those already described in other rocks in this section are to be seen.

(3) Calcareous tuff rich in aegirine and nepheline

A typical example of this type of tuff is JG811 collected at the SSE base of Kerimasi, and in the hand specimen is noticeably purple in colour. Microscopically and under reflected light, much haematite is present in part of the matrix, which elsewhere tends to be more calcitic. There are many fragments of aegirine-augite, and calcite both commonly irregular in shape and size and frequently associated with zeolite. At times the calcite and zeolite appear to be replacing large nepheline crystals, which often show euhedral, hexagonal, basal sections. Most of the ore which is quite plentiful in powdery form, is haematite. The zeolite is fibrous, with an R.I. lower than balsam; it is length slow, has straight extinction, and is probably natrolite.

The specimen JG853 was collected from the NW corner of Kerimasi and is associated with the yellow tuff and agglomerate of Oldonyo L'Engai. The thin section is interesting as it shows the junction between the finer grained calcareous rock of Korimasi, overlain by the coarser, limonitic, very open-textured tuff of Oldonyo L'Engai. The Oldonyo L'Engai tuff also contains much calcareous matter in the cementing material, and very beautifully zoned aegirine-augites; sphene is fairly common while small rock lapilli, and rarer melanite garnet are also present.

Macroscopically, JG1250, from a dry river course at the SE end of Korimasi, is compact and grey-brown in colour, with small patches of yellow material infilling some of the cavities: small fragments of minerals, dark pyroxene in particular, can be seen on the weathered surface. In thin section, the matrix is very dark, and under reflected light consists largely of iron-stained clay-like material. Aegirine, aegirine-augite and nepheline are common, together with primary and secondary calcite. Also present is a little brown, deeply pleochroic, biotite, some very dark brown garnet, at times euhedral in form, a little sphene and rock fragments, with aegirine-augite and nepheline as their main constituents.

About half a mile up the same dry river course from the location where JG1250 was collected, a less compact rock, JG 1261 was found. It is coarser grained than JG1250 and more open textured. It contains several rock fragments up to 1 inch in length. The matrix is grey with a slight purple colouration.

In thin section, aegirine and aegirine-augite are particularly common, and nepheline is often replaced by calcite, there are inclusions of fenite and tveitasite rocks. Some sphene, and dark brown melanite garnet was noticed, and the matrix consists mainly of a mixture of calcite and clay.

The specimen JG1262 was collected from a point another half mile up the same river course and is similar to JG1261 just described. Small rock lapilli are particularly common, especially biotite-pyroxenite with perovskite; rare melanite and a small octahedra possibly pyrochlore were also noted.

The general increase in the content of mafic minerals and rock inclusions, with loss calcite in the cement, leads to the fourth and last division of these calcareous tuffs.

(4) Calcareous tuffs rich in mafic minerals

The thin section of JG789 collected from the lower south-western flank of Kerimasi, shows the junction between portions of fine grained calcite with some limonite and clay material forming the cement. It contains oval shaped "ooliths" of many sizes, the larger "ooliths" having cores of rock fragments not yet completely decomposed: there is one large perovskite crystal present showing birefringence and twinning. In the less weathered portion, there are many areas of dark brown, isotropic, melanite garnet, often massive and fragmentary in form, magnetite and haematite are also present; aegirine-augite is common, and there is some biotite. The calcitic cement is less ferruginous, and a little apatite is present.

Overlying J0826 already described, is another tuff of which J0827 is a specimen. These rocks occur in a dry river course at the base of the eastern flank of Kerimasi. The specimen J0827 contains similar minerals to JG789 described above and larger fragments of different rocks, many of which can be seen in the hand specimen; biotite and aegerine-augite is common. The rock is cemented by a fine grained, open textured, grey brown matrix, and in thin section, aegirine, aegirine-augite, perovskite, garnet, biotite, magnetite, sphene, and some apatite are present. The rock inclusions are instructive, and resemble many of the types to be described in some detail later. One rock inclusion contains microphenocrysts of olivine with an iddingsite and magnetite border and resembles the nepheline-melabasalts typical of the older volcanics. Another rock fragment shows small laths, probably of feldspar with almost straight extinction, and exhibiting rudimentary flow texture. In a third rock fragment there is pale green clinopyroxene and nepheline, which latter is darkened in places through hundreds of small inclusions; perovskite was noted, and zeolites cluster around the perimeters of the nepheline. The above description only covers the most important features present but indicates the importance and variable nature of these rocks lapilli, some of the larger fragments of which are considered later.

The rock numbered J01237 was collected from a large dry river course on the south flank of Kerimasi; the slide J01237(1) is similar to the above, but many olivines, perhaps forsterite, are present, together with a large remnant of titaniferous-augite, and nepheline. The slide J01237(2) is similar, and also has one or two remains of perovskite. There is an interesting fragment of a biotite-orthoclase rock with large areas of euhedral dark brown melanite, while calcite is still abundant. Gehlenite is present. It is colourless, has one good cleavage and shows peg structure. The R.I. is high and the birefringence low; it is uniaxial negative and has straight extinction. In places it is altering to some yellow, isotropic mineral, with very low R.I. A little tremolite was also noted.

The specimen J01250 was collected from the small scarp to the SE of Kerimasi at the place where the motor track ascends the scarp. The slide 1250(1) is rich in melanite garnet which is frequently very well zoned and often shows the six-sided outline of the dodecahedron. The garnet is associated with perovskite, biotite, and aegirine-augite, while in the ferruginous stained matrix are some very altered fragments of nepheline-melabasalt. Another slide of the same rock J01250(4) is different, as the matrix is more feldspathic, but very dark brown melanite is also present; the larger garnets often having an opaque core. There is a marked difference between this portion of the tuff, and the remainder of the slide, consisting of a large fragment of tveitasite, with abundant small euhedral areas of very dark melanite garnet, associated with magnetite. Macroscopically, this rock is grey with an open textured matrix, in which are embedded all kinds of crystal and small rock fragments; a fragment half an inch around the perimeter is large; biotite is common.

Another rock collected very near to the above is JO1261, which also contains abundant melanite, often showing hexagonal crystal form in thin section, and has an R.I. of over 1.785. Brown perovskite is present, also calcite, both as primary fragments and as secondary replacement matter in the cementing matrix. Biotite is rare, melanite and green aegirine-augite predominate, although apatite, colourless clinopyroxene, and magnetite occur together with some secondary zeolite.

Another specimen JO1263, was collected from the east face of Kerimasi, where the gradient begins to increase considerably towards the summit of the mountain. It is more compact than JO1261, and embedded in the grey cement are many small rock fragments and crystals; biotite is particularly common. In the thin section JO1263 (2), there are some large deep brown birefringent crystals of perovskite, showing complex twinning and an extinction angle of 45°, the perovskite is slightly more red in colour than the darker melanite garnet, which is invariably isotropic, and is more abundant. Melanite garnet is also present in lesser amounts in a rock fragment of tveitasite; some of the clinopyroxene is brownish-green in colour, and other pyroxene has the more vivid green colour of aegirine-augite; sphene is present.

The biotite is generally very decomposed and strongly pleochroic from pale brown to a dark muddy-brown colour. Another slide JO1263(1), is similar but both slides have a dark ferruginous calcitic cementing material.

Nearly all the rock types described in fair detail above, have not been recorded in the Kerimasi area previously, and from the descriptions of the carbonatites, and some of the calcareous tuffs associated with them, most of which occur on the eastern side of the volcano, and most probably on the northern flank as well, it is evident that Kerimasi represents a rather unusual type of carbonatite complex, as it is composed essentially of calcareous ejectamenta.

The large area of surface calcrete, has been formed by the weathering of the carbonatite or sövite rocks, which occur mainly on the eastern side of the volcano. The tuffs and agglomerate of the southern flank are similar, but generally have more impurities, and are frequently stained by ferruginous products. In the south magnetite grains are especially common in some of the dry river courses. It is considered that although this change of colour may well represent a different series of rock types, it could equally as well be explained as a function of greater weathering, as the prevailing winds and rains are from a southerly direction and cloud cover on the higher slopes of the volcano is greatest on the southern side.

It is now proposed to examine petrographically some of the larger rock fragments associated with the agglomerates and tuffs of Kerimasi. Many of these rocks are identical with specimens collected from the other alkaline volcanoes in this area, Oldonyo L'Engai, Mosonik, and Shombole, and in such cases will be described collectively.

Rock fragments from Kerimasi tuffs and agglomerates

Some of the numerous rock fragments found in the tuffs and agglomerates of Kerimasi are described petrographically under the following headings:-

1. Types comparable with the rocks of the basement system
   a) An altered garnetiferous-gneiss.
2. Types comparable with the older extrusives
   a) Andesitic types.
   b) A nepheline-melabasalt.
   c) An altered dolerite.
3. Types comparable with the younger extrusives
   a) Porphyritic melanite-urtite type.
   b) A melanite-biotite-ijolite.
   c) Amphibolite-micromelteigite.
4. The pyroxene-amphibolite from Kisetov Hill, Kerimasi

1. a) An altered garnetiferous-gneiss

This rock was collected from the small hill called Kamota for locality see fig. 1 , and in thin section J0700(5) consists of large, colourless, anhedral garnets, altering along their perimeters and cracks, to a ferruginous dust, together with some very dark brown biotite, and a considerable amount of a mineral with a rather flaky habit, resembling wollastonite and always associated with ferruginous dust. In a small part of the slide there is sodic plagioclase and quartz. The rock has the appearance of a considerably altered garnetiferous-gneiss from the basement where the garnet is not the melanite variety so typical of the younger volcanics, but a colourless type in thin section, often found in the basement schists and gneisses.

2. a) Andesitic types

The slide J0700 (1) was made from a rock also collected from the small hill Kamota. The slide shows clino-pyroxene, grey to pale-grey in colour and skeletal brown hornblende, in most cases nearly completely resorbed, with a marked perimeter of magnetite. In the very ferruginous ground mass are small laths of plagioclase with indefinite extinction probably sodic andesine or oligoclase; much ore is present. This rock closely resembles some of the older andesitic volcanics. Two somewhat similar rock fragments, JG810 and JG830, were collected from the old crater hill called Kisetoy, on the east side of Kerimasi. Both slides contain clinopyroxene phenocrysts, some olivine, and basaltic hornblende; the dark ground mass contains much magnetite, a mineral resembling iddingsite, and a fair amount of secondary carbonate, whilst small laths of feldspar are fairly common. A feature of both of these rock fragments, is the abundant small octahedra of perovskite, visible under high power. Deans[1] reports he found similar perovskite in JG1234, which on analysis by Mr.R.Pickup, of the Colonial Geological Surveys, Mineral Resources Division, London was found to contain 50% TiO_2 and 2% Nb_2O_5. Deans mentions that the absence of zircona indicates this perovskite is not uhligite, another type of perovskite previously reported from this district.

Another point of interest is that the pyroxene phenocrysts are nearly always surrounded by a border, rich in ore, but containing plagioclase laths and other minerals, which are often orientated with their long axes parallel to the side of the pyroxene phenocryst. This suggests that the pyroxene, did not include the ground mass material whilst growing, but succeeded in pushing it aside and concentrating it in the above unusual manner.

2. b) Nepheline-melabasalt

A somewhat similar slide is that of JG1230; the rock was collected from the south flank of Kerimasi, and contains many small olivine crystals considerably altered to iddingsite. The rock is fine grained. Some clinopyroxene

(1) Deans to Guest personal communication.

and magnetite are present, situated in very low birefringent, if not isotropic, interstitial material; which, in places, shows feldspar lamellar twinning, but elsewhere is considered to be most probably nepheline with some analcime. The rock is allied to the nepheline-melabasalts. Macroscopically, it is dark and compact, with very small vesicles, some being infilled by white calcitic material. The rock fragment is over two inches in length, and is larger than any agglomerate particle previously described. It is embedded in a grey calcareous cement, with a variety of other rock fragments and minerals, one of these being a small chip of granitic-gneiss.

8. c) An altered dolerite

Another of these more unusual rock fragments, J01234 was collected from a calcareous tuff in a large dry river, on the south flank of Korimasi. Macroscopically, the rock fragment is amygdaloidal, and the ground mass is fine grained and dark, with some patches of black ore, and other areas of lighter lath shaped material. In thin section some of the minerals show considerable decomposition. There are large fragments of an amphibole with a brown border, and a pale green core, associated with much opaque dust; in places granular sphene is common. Some pyroxene and apatite are present. In the ground mass, there is much pale-green to brown fibrous chlorite, at times showing ultra-blue birefringent colours, which is associated with another isotropic, high R.I. mineral, resembling chlorite. In ordinary light there are laths of feldspar, which under polarised light, are very altered and albitised, some of these show traces of ophitic texture.

The rock is thought to resemble an altered dolerite, where the pyroxene has been mostly converted to amphibole. At onetime, this rock may have resembled some of the older extrusives, as no dolerite dykes or sills were noticed in the basement in this region.

3. a) Porphyritic melanite-urtite type

A specimen JO807 collected from the ridge on the south-east side of Kerimasi, shows under the microscope, common porphyritic, euhedral, rather decomposed nepheline crystals, associated with areas of granular calcite, nearly opaque melanite - at times enclosing small flakes of fresh aegirine-augite. All are embedded in a very decomposed calcareous and ferruginous ground mass, with a little unaltered nepheline, and small ragged aegirine-augites. The rock is considered to be an altered porphyritic melanite-urtite, similar examples of which are considered later amongst the more common extrusive types, but these generally tend to be more melanocratic.

3. b) A melanite-biotite-ijolite

A slide labelled JO814(2) has some points in common with the above, but is not so decomposed. It consists of large nephelines, showing signs of alteration along cracks and imperfect cleavage planes, and abundant dark-brown, sometimes euhedral melanite, which is invariably associated with pleochroic olive brown to pale-brown biotite, and colourless diopside. There is one large red to brown broken fragment of perovskite, showing very fine twinning under polarised light: magnetite is also present, and is generally surrounded by garnets. The rock is called a melanite-biotite-ijolite, and like JO807 is gradational towards the urtite-ijolite-melteigite type of nephelinites to be described later.

3. c) The amphibole-micromelteigite

The rock JO815 was collected from a point about half way up the ridge on the south-east flank of Kerimasi. Macroscopically it is rich in mica and is considerably sheared. In thin section there are also signs of shearing, especially around the margins of the large, fragmentary, pleochroic, light-brown hornblende. Relatively common in the slide as a whole, which is lacking in mica, are small laths of pyroxene, probably diopside, associated with clusters of pale green diopside fragments. There are several pockets of granular nepheline, with some orthoclase showing rare carlsbad twinning.

The rock is called an amphibole-microsoltoigite and is an unusual type gradational to the melanephelinites.

4. Pyroxene-amphibolite

Another amphibole-rich rock fragment JG818, was collected from the calcareous tuff making up the volcanic crater-hill called Kisetey. In the hand specimen it is a very dark open-textured rock, rather friable, and consists of masses of small black amphibole, with a little light coloured calcareous material infilling some of the cavities. The grey weathered surface is both ferruginous and calcareous. Microscopically, the rock is seen to consist almost entirely of amphibole, pyroxene, opaque ore, and relatively rare interstitial colourless minerals. The amphibole is probably similar to larger dark nodules of amphibole collected from the same calcareous tuff of which JG817 described below is an example. The clinopyroxene of JG818 has an extinction angle Z C of from 58° to 60° it is pale green in colour, and some flakes show oscillatory colour zoning. The ore is magnetite, and occurs abundantly as a dark border on the edges of both the amphibole and pyroxene. Interstitially, calcite is the most common colourless mineral, and with zeolite and some nepheline is only accessory in amount. The amphibole encloses the pyroxene, and is therefore considered to be of later origin.

A chemical analysis with norm and a modal analysis are given below:-

TABLE NO. 13

Chemical analysis of JG818 pyroxene-amphibolite

	JG818	1.	2.	
SiO_2	39.72	43.53	33.27	
Al_2O_3	8.58	7.24	2.80	
Fe_2O_3	8.05	11.10	14.30	
FeO	7.42	8.70	5.63	
MgO	11.44	11.51	12.35	
CaO	12.92	10.10	17.50	
Na_2O	2.23	2.88	1.42	
K_2O	.98	1.39	1.82	
H_2O+	1.09	1.34	.66	
H_2O-	.46	.43	.08	
TiO_2	7.03	1.90	9.86	
P_2O_5	.04	tr	.40	
MnO	.17	n.d.	.07	
CO_2	Nil	Nil	tr	
	100.15	100.21	tr	ZrO_2
			.02	Cl
			.04	BaO
			100.17	

NORM JG818

Quartz	1.20	
Orthoclase	6.12	
Albite	18.86	
Anorthite	10.29	
		36.47
Diopside:-		
$CaOSiO_2$	22.39	
$MgOSiO_2$	19.30	
Hypersthene	9.30	
Magnetite	3.94	
Haematite	5.44	
Ilmenite	1.34	
		61.71
plus H_2O		1.55
		99.73

JG818 C.I.P.W. classification:- IV (1), 2 (1), 1. 3.
Brandbergiase.

Analyst W.H.Herdsman.

Niggli values: si 75.75; al 9.84; fm 57.75; c 26.90;
alk 5.50; k .3029; mg .592; qz -46.25

Modal composition JG818, Five traverses on two different slides

Slide number	JG818 (1)		JG818(2)			
	Range	Average	Range	Average	Range and Average of both slices	
Calcite	0 - 4.98	.99	0.00 - 4.43	1.83	0.00 - 4.95	1.41
Hornblende	50.30 - 78.93	63.16	19.32 - 69.16	50.75	19.32 - 75.93	56.96
Zeolite	0.00 - 2.65	1.45	.23 - 3.38	1.59	0.00 - 3.38	1.52
Opaque ore	1.59 - 17.50	8.35	14.24 - 41.30	24.83	1.58 - 41.30	16.59
Pyroxene	14.24 - 45.45	25.99	7.89 - 19.71	19.71	7.89 - 52.91	22.76
Nepheline	tr	tr	tr - 2.67	1.39	0.00 - 2.67	.69
Apatite	tr	tr	0.00 - .18	.04	0.00 - .18	.02
		99.94		100.13		99.95

	1.	2.
Aegirine-augite	-	54
Orthopyroxene	5	-
Hornblende	91	-
Biotite	-	21
Ores	-	10
Perovskite	-	14
Apatite	-	1
Feldspar	4	tr
Plagioclase	-	-

1. Davainite, Near Loch Ben Davain, Scotland. Analyst: not stated. Wyllie and Scott. Geol. Mag. Vol.X 1913 pp. 499-505. Calculated mode by Troger, Spezielle Petrographie, 283.
2. Bebedourite, Brazil. Troger analyst. Troger, Spezielle Petrographie 279.

Two analyses given above for comparison purposes with the pyroxene-amphibolite JG818, are classified by Johannsen[1] as perknites; the davainite belonging to a perknite group with less than 5% modal ores, and the bebedourite to a group with more pyroxene and ore. The latter is one of the biotite-bearing pyroxenites which are considered in greater detail later. The davainite consists essentially of "brown hornblende" which is paramorphic after pyroxene, the total amounts of other minerals such as hypersthene and feldspar being small. Macroscopically this rock is granular and appears to be composed of coal-black crystals of hornblende which, in thin section, show dark-brown to light-yellow pleochroism, and the hornblende generally has cores of diallage, regarded by Wyllie and Scott[2] as the original mineral from which the hornblende was formed. The analysis of JG818 resembles that of JG1254 a biotite-pyroxenite see table 15 , but JG818 contains much less CaO; JG818 is certainly allied to these ultra-basic rocks.

According to the calculated norm of this pyroxene-amphibolite the salic minerals are more than half as abundant as the femics, whereas in the actual modal analysis the femics definitely predominate and the total light coloured minerals are generally less than 5%. From the modal analysis, amphibole predominates, and the rock is therefore called a pyroxene-amphibolite. An unusual feature shown in the chemical analysis is the rather high figure for TiO_2 - 7.05%, this must be accounted for in ore, when all the TiO_2 was actually used to make normative ilmenite - or in the amphibole and pyroxene.

In this connection, the chemical analysis of JG817, a fragment of hornblende from the same tuff of Kisetey, is instructive, and is quoted in full below. The analysis shows

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(1) Johannsen A. A descriptive petrography of the igneous rocks. Vol. IV pp. 448 and 453.

(2) Wyllie B.K.N. and Scott A. The plutonic rocks of Garabal Hill. Geol. Mag. X. 1913 pp499 - 508.

3.85% TiO_2. Iddings[1] quotes eight examples of hornblende with more than 4% TiO_2 at least three of these came from tuffs, two of which are described as basaltic tuffs

TABLE NO. 14

Chemical analysis of amphibole JG817 from Kisetey

	JG817	No.1	No.2	No.3
SiO_2	41.34	40.85	40.10	40.06
Al_2O_3	10.01	9.89	10.08	14.69
Fe_2O_3	11.86	8.02	7.81	10.84
FeO	0.92	3.99	9.66	0.57
MgO	15.67	12.47	9.74	12.38
CaO	11.69	12.16	10.60	12.80
Na_2O	2.25	2.01	3.18	1.89
K_2O	1.04	0.93	1.60	1.77
H_2O +	.24	0.10	0.00	-
H_2O -	.21			
TiO_2	3.85	0.47	4.55	4.99
P_2O_5	tr	-	0.63	-
MnO	.13	0.12	0.15	-
CO_2	-	-	-	-
F	-	0.28	0.31	-
NiO	-	0.10	-	-
	100.01	99.98	101.01	100.49

Analyst of JG817 R.O.Roberts, M.Sc., F.R.I.C.

No.1 Hornblende in a tuff, Monte Rosso, Lincoa.
No.2 Hornblende in haunite, Haus, Norway.
No.3 Hornblende in basalt tuff, Ohmberg, Vogelsberges.

From the analyses it will be seen that JG817 is remarkably rich in MgO and poor in FeO. The optical properties of this hornblende have not been fully investigated but it can be provisionally stated that the maximum extinction angle of the amphibole is $Z \wedge C$ 12°, Z is dark brown, and X and Y lighter brown in colour. 2V is about 34°. Without any further information at this stage, the amphibole would appear to be a member of the rather large common hornblende group, where Ti may proxy for Fe", Fe"', or Al, etc.

Another somewhat similar large ejected block of amphibole JG671, was picked up in the grey tuff, whilst descending the western flank of Oldonyo L'Engai. Macroscopically this specimen is darker, and black rather than dark

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(1) Iddings J.P. Rock Minerals. Wiley 1911 p.352.

brown in colour. Preliminary optical investigation shows the extinction angle Z ∧ C varies between 11° and 16°, and 2V between 43½° to 48⅔° by U-stage measurements in ordinary light, and between 44½° to 48½° in sodium light.

It is interesting to note that ejected fragments of hornblende are common to both the volcanoes of Kerimasi and Oldonyo L'Engai, and this similarity automatically leads to the next division of rock types consisting of rocks which are common to both of these volcanoes.

Biotite-pyroxenites of Kerimasi and Oldonyo L'Engai

A block of black rock JG1254 was picked up, not in situ, in a dry river course on the southeast flank of Kerimasi, and is a typical inclusion in the darker-coloured calcareous tuffs common to this side of the mountain. Macroscopically, JG1254 is fine grained, heavy and black, but lighter coloured on the weathered surface; on the fresh surface it is extremely friable due to the high biotite content. Under the microscope, it consists almost essentially of olivine-green aegirine-diopside, generally interlocking with slightly larger flakes of very pleochroic biotite, which vary from straw colour to olive brown. Small granules of magnetite are also present and small quantities of an interstial mineral resembling orthoclase and nepheline. All the minerals are remarkably fresh. Using immersion liquids and a Leitz-Jelly refractometer, the Ny of the biotite was found to be 1.62.

A chemical analysis of this rock with norm, Niggli values and a modal analysis are given below in table No.. Regarding the mode, the same apparent error which was mentioned in reference to the perknites above, was again noted, that is, in the modal analysis the salics are much lower than the estimated value for salics in the norm.

TABLE NO. 15

Chemical analysis of biotite-pyroxenite, JG 1254 from Karimosi

	JG1254		1.	2.	3.
SiO_2	41.35		45.11	39.02	36.7
Al_2O_3	9.31		9.80	6.81	4.1
Fe_2O_3	6.90		6.05	7.30	9.4
FeO	6.37		1.87	3.24	6.0
MgO	13.48		15.61	9.66	11.0
CaO	16.62		12.00	22.03	19.7
Na_2O	.95		1.43	.60	.6
K_2O	1.12		3.14	.40	1.0
H_2O +	.50		1.03	.11	.9
H_2O -	.32		0.06	.02	.4
TiO_2	1.86		1.52	3.15	7.4
P_2O_5	.43		0.08	.33	1.3
MnO	.41		0.15	.10	.1
CO_2	nil		-	1.82	.2
	100.08	Cl	tr	.07 BaO	.05
		Cr_2O_3	.11	.0003 SrO	.05
		BaO	.08	.00 F	.1
				.04 S	.1 SO_3 & S
			100.36	100.05	100.0

	4.	5.
SiO_2	43.35	44.39
Al_2O_3	9.07	6.37
Fe_2O_3	6.26	6.11
FeO	2.63	4.66
MgO	15.74	14.20
CaO	12.20	17.02
Na_2O	.44	.50
K_2O	4.74	2.35
H_2O +	.59	.33
H_2O -	.07	.03
TiO_2	4.30	3.01
P_2O_5	tr	.26
MnO	.09	.10
CO_2	.04	.04
Cl	tr	.04
F	.11	.04
S	tr	.03
Cr_2O_3	.06	.03
V_2O_3	.04	.05
NiO	.06	.01
BaO	.30	.16
SrO	none	.03
Li_2O	tr	tr
	99.79	99.89
Less O	.04	.03
	99.75	99.86

Analyst of JG1254 W.H.Herdsman.

1. A biotite-pyroxenite occurring in volcanic ejectamenta of Vesuvius, analysis by Rittmann. Johannsen, Descriptive Petrography IV p.450.
2. Pyroxenite, analysis no. 33 from Alnö, analyst R.Blix. von Eckermann on Alkaline district of Alnö p. 69.
3. Average of the Iron Hill pyroxenite as estimated from the proportions of the types present in the mass by E.S.Larsen. U.S.Geol. Survey. Professional Paper 197 -A.
4. Biotite-pyroxenite, Bufumbira, Analyst H.F.Harwood. Total includes CuO=.03. Holmes and Harwood. The petrology of the volcanic area of Bufumbira, Geol. Surv. Uganda. Memoir III Pt.2. p.30.
5. Biotite-pyroxenite, Katwe crater, Toro-Ankole Field, Uganda- analyst H.F.Harwood. loc. cit. p.30.

JG1254 C.I.P.W. classification: IV, (1), 2.(2), 1 (3), 2 paloe.

Niggli values:- si 73.07; al 9.03; fm 53.20; c 35.21; alk 2.60; k .44; mg .65; qz - 30.39.

NORM of JG1254

Anorthite	17.70	
Orthoclase	4.10	
Nepheline	4.50	
Leucite	1.90	
Diopside	16.70	28.18
Wollastonite	21.50	
Olivine	19.32	
Magnetite	9.93	
Ilmenite	2.63	
Apatite	1.01	
H_2O	.90	71.02
		.90
	100.10	100.10

Modal Composition

J01254 - Results of Four Traverses On One Thin Section

	J01254 Range	Average	No.1	No.2	No.3
Pyroxene	21.74 - 74.90	56.30	plus 60	80.0	61
Biotite	0.09 - 42.76	19.90	plus 37	4.1	15
Ore	8.76 - 22.26	15.43		-	-
Orthoclase	0.00 - 13.45	5.07		-	tr
Nepheline	0.00 - 7.24	2.21		-	tr
Glass			present	-	-
Titano-magnetite				9.2	-
Calcite				4.2	-
Melanite				1.7	tr
Apatite				0.7	2
Pyrite				0.1	-
Albite				-	tr
Sphene;				-	tr
Olivine				-	tr
Perovskite				-	7
Magnetite				-	11
Ilmenite				-	3
Carbonate (primary				-	1
		99.99	+ 97	100.0	100

Johannsen[1] describes the biotite-pyroxenite from Vesuvius as the only rock found in his family 4111. Macroscopically, the rock from Vesuvius has been described as a grey-black rock with phenocrysts of biotite 2 cm. in diameter. In five of the six analyses quoted above, K_2O exceeds Na_2O, a reversal of the general condition noted in all the other rock analyses from this area although this appears to be a feature of these ultra-basic rocks. Also the Kerimasi rock contains less TiO_2 but more P_2O_5 when compared with the three other pyroxenite types. These points are worth stressing as in some of the other analyses already mentioned, the TiO_2 content has been noticeably high.

A similar rock was collected as an ejected block (JG1274) from the grey ash on the summit of Oldonyo L'Engai. Microscopically the slide JG1274(4) consists essentially of rather fragmentary clino-pyroxene, generally almost colourless but with pale green patches which is interlocked with abundant, but rather fragmentary biotite. Perovskite, showing birefringence and twinning under polarised light is common, but is rarely euhedral, whilst magnetite is uncommon. In the thin section, the light coloured minerals are conspicuously absent, although apatite was noted interstitially in some places. A feature of the slide is the relatively large amount of perovskite present, and the TiO content must in this case be considerably higher which, compared with JG1254, appears to be more in keeping with the other rocks analysed from the Oldonyo L'Engai district.

TiO_2 is particularly high also in the two rocks from Bufumbira region quoted above, where biotite-pyroxenites are common as ejected blocks, or inclusions in certain lavas,

(1) Johannsen A. A descriptive petrography Vol.IV p.450.

The Younger Extrusives

Oldonyo L'Engai, Mosonik, Shombole

1. Short summary of previous geological work

It is only to be expected that an active volcano such as Oldonyo L'Engai, the mountain of God to the local Masai, should have been known from the earliest days of European exploration, and , according to Richard(1) it is mentioned on one of the first maps made of East Africa, the Mombasa Mission Map of 1850.

In 1882/3 Dr.G.A.Fischer(2) passed through the area, and subsequently O.Mügge(3) in 1886, published petrographic descri-ptions of the rocks collected on this expedition; this appears to be the first geological work on this area.

In 1873 the Rev. Charles New(4) published a map showing the estimated position of Oldonyo L'Engai, which was apparently near or on one of the slave routes.

During the next decade, there were several German expeditions to this part of Africa, and the rocks collected on some of these expeditions were subsequently described by petrologists. For instance in 1892/93 O.Baumann(5) collected geological specimens, later described by Lenk(6). Similarly, in 1896/97 Dr.Max Scholler(7) was in the neighbourhood of Oldonyo L'Engai, accompanied by a geologist Kaiser, who

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(1) Richard J.J. Volcanological Observations in East Africa - Oldonyo L'Engai. The 1940-41 eruption. Jour.E.African Nat. Hist. Soc. Vol. XVI No.2 & 3 (71 & 72) pp.89-103.
(2) Fischer G.A. Bericht Reise im Masailand 1882/83. Mitt. d Geogr. Ges. Hamburg. pp. 36-87.
(3) Mugge O. Untersuchung der von Dr.G.A.Fischer gesammelten Gesteine des Masailand. Mitt. Geogr. Ges. Hamburg. 1882-83, and Stuttg.N.J. Min (N.J.B.B.) IV. 1886. pp.576-609.
(4) New Rev. Charles Life, Wanderings and Labours in East Africa. London 1873.
(5) Baumann O. Durch Masailand zur Nilquelle. Berlin 1894 pp. 368.
(6) Lenk H. Über Gesteine aus Deutschostafrika. Aus Baumann Durch Masailand zur Nilquelle. Berlin 1894 pp.26-94.
(7) Scholler M. Äquatorial-Ostafrika-Expedition 1896/97 DEZ 1898.

referred to Oldonyo L'Engai as Duonio Ngai: Kunzli E.[1] described rocks from this expedition in 1901. Also in 1896, von Trotha[2] using camels as transport animals, passed by "Mount Ngai".

After the turn of the century, Prof. C. Uhlig[3a, 3b] Prof. F. Jaeger[4] and latterly Reck H.[5] made valuable written contributions to the knowledge of the Oldonyo L'Engai district. Reck in particular described the volcano in some detail.

The first World War suspended further explorations to some extent, although Hobley[6] published his valuable account of the 1917 eruption of Oldonyo L'Engai, and later Reck H.[7][8][9] wrote three more papers concerning Oldonyo L'Engai, the last one dated 1924.

In 1935 Erdmannsdorffer O.H.[10] stressed the apparent importance of wollastonite in the rocks from the Oldonyo L'Engai volcano; and finally in 1940-41, an eruption of the volcano was faithfully recorded by Richard J.J.[11] with some descriptions and analyses.

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(1) Kunzli E. Die petrogr. Ausbeute d. Scholler'schen Exped. in Aequat-Afrika, Viertelj. Naturforsch. Gesellschaft in Zurich 1901.

(2) Trotha von. Meine Bereisung von Deutsch-Ostafrika. Berlin 1897.

(3a) Uhlig C. Der sogenannte grosse Ostafrikanische Graben zwischen Magad (Natron-See) und Laua ya Mueri (Manyara-See) Geogr. Zeit. Vol. 13 1907.

(3b) Uhlig C. Die ostafrikanische Bruchstufe. Mitt. aus den Deutschen Schutzgebieten. Berlin 1909.

(4) Jaeger F. Das Hochland der Riesenkrater und die umliegenden Hochländer Deutsch-Ostafrika 1906/07 Expedition - Mitt. aus den Deutschen Schutzgebieten. Berlin 1911.

(5) Reck H. Vulkanolog. Beobacht an der Deutsch-Ostafrikanischen Mittelland-Bahn-Zeitschr. f. Vulkan 1914 pp.70-86.

(6) Hobley C.W. 1918. A Volcanic Eruption in E.Africa. Journ. E.African Nat. Hist. Soc. VI.

(7) Reck H. and Schulze G. 1921 Ein Beitrag zur Kenntnis des Baues und der Jungsten Veranderungen des L'Engai-vulkans im nordl. Deutsch. Ostafrika. Zeitschr.f. Vulkanol 6. pp. 47-71.

(8) Reck H. Uber der Ausbruch des Oldonyo L'Engai in Deutsch-Ostafrika im Jahre 1917 Berl. Zeitschr. f. Vulkanol 7. pp.55-6.

(9) Reck H. 1924 L'Engai Bilder. Berl. Zeitschr. f.Vulkanol 8. pp.173-74.

(10) Erdmannsdorffer O.H. 1935 Uber Wollastonitturtit und die Entstehungsweisen von Alkaligesteiner Sits. ber. Heidelberger Akad. Wiss. Math. Nat. Kl. (B) pp.1-23.

(11) Richard J.J. Volcanological Observations in East Africa - Oldonyo L'Engai. Jour. E.African Nat. Hist. Soc. Vol.XVI.

As far as can be ascertained, no other observations were made on the behaviour of the volcano, until it was climbed in 1949 by Dr. Reusch and two other Europeans, and in 1950 and 1951 by the writer.

From the above summary, which covers the main contributions concerned with geological matters written about this area, it will be appreciated that although individual petrographical descriptions are fairly common and thorough, see especially Mügge[1] and Rosenbusch[2] little stratigraphy had been done, and the only geological maps, resulting from these studies are useful but extremely approximate.

It is to be regretted that more often than not, the exact localities of specimens are unknown, although in a virtually unmapped country, this is only to be expected.

Before describing the specimens collected in 1950 and '51 a brief survey will be made of the younger extrusives identified by some of the German workers mentioned above.

a) <u>Oldoinyo L'Engai</u>

In 1882-83 Mügge gave lengthy descriptions of nephelinites, together with some mineralogy of the mineral constituents, and he also described feldspar-basalt, aegirine-andesite, phonolitic-theralite and basalt; although some of these may well belong to the older extrusive series.

In 1906/07 Kunzli described Kaiser's specimen No.21 as a nepheline-phonolite, and his specimen No.23 as a nepheline-tephrite with nephelinite.

In 1907 Uhlig reports of Oldoinyo L'Engai, that nephelinite with rather large nepheline phenocrysts is the dominant lava, but seems to occur only on the lower third portion of the mountain, composed elsewhere of tuffs; he noted the white soda-salts on the upper surface of the volcano.

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(1) Mügge O. Untersuchung der von Dr. G.A. Fischer gesammelten Gesteine des Massailand. Mitt. Geogr. Ges Hamburg. 1882-83 and Stuttg. N.J. Min (N.J.B.B.) IV. 1886. pp. 576-609.

(2) Rosenbusch H. 1908. Mikroskopische Physiographie etc.

In 1914 Reck described in detail his ascent of the volcano, and noted the "Devils needle" a thin cone on the northern crater rim, about 40-50 m above the crater floor, which has since been blown away by subsequent eruptions. Reck states that the volcano is an ash cone, as lava flows were not noted. He states that the petrological examination of the collected materials had still to be carried out.

The 1917 eruption of Oldonyo L'Engai was recorded by Hobley in 1918; it was heralded by the occassional appearance of steam clouds; the volcano erupted from January until June, and lava flows were noted together with much grey ash.

Previously in 1908 Rosenbusch mentions nephelinite and normal nephelinite with a glass base from Oldonyo L'Engai, and Brogger[1] in 1921 describes an ijolite from Oldonyo L'Engai.

Some years later in 1935, Erdmannsdorffer noted the optical properties of some of the minerals in the rocks he described, which included syenite, and nepheline-syenite, and in the ijolite-urtite series, he included one of Mugge's nephelinites. He published a new analysis of a wollastonite-ijolite from the north foot of oldonyo L'Engai, and a modal analysis of a wollastonite-urtite, both of which are given in the table below, and are compared with two similar rock analyses, one from Korimasi.

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(1) Brogger W.C. Die Eruptivgesteine Des Kristianiagebeites (IV) 1921, p.40.

TABLE NO. 18

	1.	2.	3.	4.
SiO_2	39.26	43.04	47.2	48.50
TiO_2	1.68	0.94	2.4	0.39
Al_2O_3	15.70	15.04	7.0	6.17
Fe_2O_3	4.03	4.15	0.9	1.52
FeO	3.14	2.78	0.1	1.84
MnO	-	-	-	0.09
MgO	3.62	2.17	-	3.60
CaO	16.00	19.03	35.9	36.00
BaO	-	-	-	0.09
Na_2O	7.50	7.61	5.7	0.55
K_2O	3.03	3.49	1.3	1.23
H_2O	0.94	0.34	0.5	0.66
CO_2	-	0.84	-	0.01
P_2O_5	3.28	0.49	-	0.11
	99.66	100.42	99.8	100.41
D	2.903	-	-	-
Anal.	Eyme	Eyme	-	Mariol
si	76.2	92.0	97.6	94.6
al	18.0	20.5	9.5	5.9
fm	29.8	21.8	1.4	18.1
c	34.5	39.2	79.8	73.4
alk	17.9	18.5	9.3	2.6
k	0.21	0.23	0.10	0.60
mg	0.38	0.60	-	0.07
Nepheline	48.72	43.9	23.8	-
Pyroxene	30.00	22.1	-	-
Garnet	12.83	5.7	-	-
Wollastonite	-	25.2	72.1	-
Titanite	0.90	-	-	-
Perovskite	-	-	4.1	-
Magnetite	2.18	1.3	-	-
Apatite	7.76	1.1	-	-
Kalkspat	-	1.9	-	-

1. Ijolite from Kerimasi, reported by Finckh.
2. Wollastonite-ijolite, from north foot of Oldonyo L'Engai, from the Prussian Survey.
3. Wollastonite-urtite, too small a piece for chemical analysis. The figures are derived from a modal analysis of the constituents, reckoning the nepheline from 10 nepheline-syenites, the wollastonite from analysis of Wulf, and perovskite from analysis of Sauer from Oberwiesenthal.
4. A rock near the wollastonite-urtite, an "endomorphic" wollastonite-leucite-pyroxene rock from Monte Somma.

Erdmannsdorffer also mentions numerous fragments of basement rock in the tuff of Oldonyo L'Engai. He goes on to describe at some length nephelinites from the area as a whole; one type with affinities towards the ijolite-melteigite series, and the second type more like the nepheline-tephrites and basalts, and melilite-basalts.

Holmes and Harwood[1], para. 114, mention Oldonyo L'Engai in some detail; quoting from Erdmannsdorffer they point out that besides nephelinites and phonolites, found amongst the ejected blocks of gneisses and amphibolites of the country rock there have also been recognised blocks of the following types:-

Biotite-hornblendite, hornblendite, appinite, quartz-biotite-diorite. Olivine-biotite-pyroxenite, shonkinite, alkali-syenite. melteigite, ijolite, malignite. Wollastonite-apatite-pyroxenite, wollastonite-ijolite.

Finally, Richard,[2] who studied the 1940-41 eruption, described the tuffs and rocks collected, and two new analyses of nephelinites were made, L7 and L11 which are quoted in the table below. Analyses of a brown powder and a white crust collected from Oldonyo L'Engai are given under the section on Lake Natron, see table no. 27 .

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(1) Holmes A & Harwood H.F. 1937 The volcanic area of Bufumbira. Geol. Surv. of Uganda. Memoir III.
(2) Richard J.J. Volcanological Observations in East Africa. Oldonyo L'Engai. Journ.E.African Nat. Hist. Soc. Vol. XVI.

TABLE NO. 17

	L7	L11
SiO_2	30.60	42.44
TiO_2	2.01	2.15
Al_2O_3	11.40	12.20
Fe_2O_3	6.70	6.33
FeO	3.06	3.14
MnO	.33	.34
CaO	17.54	10.73
MgO	1.90	1.05
K_2O	5.58	5.19
Na_2O	7.84	14.24
P_2O_5	1.03	.60
CO_2	2.54	.50
S	.20	.00
F	.43	.28
H_2O -	1.31	.46
H_2O +	.30	.19
	100.46	99.82
Loss O_2 equiv. to F	.10	.12
	100.26	99.70
Loss O_2 equiv. to S	.12	.00
	100.14	99.70

Analyst Miss A.F.R. Hitchens B.Sc., A.I.C.

Niggli values

L7 - si 85.5; al 14.4; fm 23.9; c 40.4;
alk 21.1; mg 0.46; k 0.32; ti 3.0;
p 0.9; qz -93.0

L11 - si 94.4; al 16.0; fm 23.4; c 25.6;
alk 35.0; mg 0.10; k 0.14; ti 3.0;
p 0.4; qz -157.0

b) Mosonik

In 1907 Uhlig noted the different form of this mountain compared with the other younger volcanoes, and both he and Jaeger at first thought it was composed of basement or sedimentary rocks. Subsequently they believed the rather unusual form was probably due to faulting but Uhlig later gave the impression that he regarded it as formed by fissure eruption. Many nephelinites were collected, which were found to be closely related to those of Shombole and Oldonyo L'Engai. I am grateful to Mr.T.Deans who pointed out to me that in the middle of Brögger's memoir, p.249 to be exact, a rock from Mosonik is mentioned in which possible pyrochlore had been identified. In the same work p.358, under the chapter on eruptive rocks with primary calcite, Brögger calls the rock ringite, and compares it with similar types from the Fen district.

Rosenbusch in 1908 notes p.1433, a nephelinite with sodalite from this mountain, and on p.1434, a normal type nephelinite collected from 1100 m.

c) Shombole

Under "Guasso Nyiro" possibly Waso Nyiro, a river entering Lake Natron to the west of Shombole, Hunsli in 1896/7 described phonolitic-trachytes, trachytes, melaphyre, olivine-melaphyre and obsidian - a glassy alkaline trachyte, all of which were most probably collected from over the border in Kenya, and appear to be referred to the older extrusives in the present classification.

In 1907 Uhlig, noted nephelinites, similar to those of Oldonyo L'Engai, and stresses a point which has been borne in mind thoughout this thesis (translated) "similarity in volcanic rocks is certainly no proof of contemporaneity" Uhlig was undecided about Shombole ever having had a crater. Rosenbusch, in 1908, on p.937 describes from the NE end of Lake Natron, a trachyte with carbonate, and on p.1434, to the N. of Lake Natron, a nephelinite with zeolite and calcite.

Both specimens must have come from very near to Shombole, and may well have originated from that mountain.

In 1935 Erdmannsdorffer describes a rock from this locality under the ijolite-urtite heading.

d) <u>Miscellaneous younger volcanics</u>

In 1894, Lenk described a sodalite-trachyte from the Lake Natron area. Some rocks collected by Kaiser, were described by Künzli in 1896/97, as coming from the river Pesinj, on the west side of Lake Natron; the rocks numbered 32-37 are in the melaphyre range, No.31 is an olivine-basalt, 35 a picrite-porphyry, and No. 36 a basalt. From Ndalalani, to the SW of Lake Natron, he mentions a phonolite and a nephelinite. Many of the above rock types, appear to fall into the present older extrusive classification.

Some years later in 1908 Rosenbusch described a pantellerite-trachyte from the NW of Lake Natron, and from Embagai, a large crater to the south of Kerimasi, a block of nephelinite from a tuff collected by Uhlig and Jaeger on the Otto Winter Expedition.

Very many years later in 1935, Erdmannsdorffer, under the heading of an ijolite-urtite series, mentions a nepheline-free pyroxenite from a ruined crater on the SW corner of Lake Natron. A biotite-peridotite from an ash crater between Kerimasi and Gelai, and two inclusions in nephelinite; one a hornblende-gabbro from the SE corner of Lake Natron, and the other, an amphibolite, from the SW corner of Lake Natron. He gives general descriptions of two types of nephelinites from rocks of the Oldoinyo L'Engai region.

8. <u>Geological sequence, Oldonyo L'Engai</u>

The geological sequence of this volcano is as follows, see also the geological map of this area, fig. 1 .

Summit region	Melanephelinites, as ejected blocks, with ijolite-melteigite-biotite-pyroxenite affinities.
	Much volcanic ash, grey in colour, and white soda.
About 9,000 feet	Nephelinitic-phonolites (JG866), lava flow.
	Ejected rocks of melanephelinite, with ijolite-biotite-pyroxenite affinities.
Below 9,000 feet to	fenites / tveitasites — both as ejected rocks.
	much grey ash and tuff.
Base of southern flank	
	nephelinitic-phonolite (JG 801,845,846), lava flow.
Base of northern flank	
	melilite-basalt JG838, lava flow.

Petrographical accounts of all these rocks types will be found in the following sections. No stratigraphy has been worked out for any of the other volcanoes.

The petrography of certain ejected rocks found only on the volcano of Oldonyo L'Engai

Having already described in some detail, the calcareous rocks and tuffs of Kerimasi, and the more unusual rock fragments from those tuffs, some of which were seen to be comparable to similar rocks from Oldonyo L'Engai; it is now time to describe certain ejected rocks collected only from Oldonyo L'Engai, and these can be divided into four groups:-

1. A nephelinite with urtite affinities.
2. A trachytic type.
3. Fenite.
4. Tveitåsite.

1. Nephelinite with urtite affinities

The rock JC650 was found as a block in the most westerly river course originating from the volcano itself. Under the microscope, it consists of predominant large interlocking, generally rather euhedral nephelines, containing very many inclusions of the other minerals mentioned. Aegirine in small laths and needles is common, and is strongly pleochroic in the larger laths from an almost opaque dark brown to very dark green, often the cores consist of paler coloured aegirine-augite with a much wider extinction angle. Also present in smaller amounts is a very decomposed, fibrous, colourless amphibole, associated with ferruginous dust and a little sphene.

Similar rock types will almost certainly be found in time, from the Lake Natron area, and the other alkaline volcanoes in the vicinity, as this type is the leucocratic member of the nephelinites and melanephelinites, representing the plutonic series urtite to melteigite. Numerous examples of ijolitic and melteigitic types of nephelinite will be described later, but so far only this one example has been found with urtite affinities.

2. A trachytic-type

Overlying the outcropping lava flow forming a ridge on the higher western flanks of Oldonyo L'Engai, is a thin layer of green compact tuff, from which the rock fragment J0807 was collected. Macroscopically it is a rather weathered, fine grained rock with a granular texture. In thin section it shows trachytic texture. The slide consists largely of sanidine phenocrysts in a groundmass of sanidine laths. A little pale green aegirine-augite was noted with magnetite, associated with a dark brown, fragmentary mineral, of similar habit to the amphibole in the Gelai amphibole-phonolitic-trachytes and the Kibangaini trachytes, which latter, the rock closely resembles. Interstitially, there is much secondary calcite present, with zeolites and ferruginous dust.

3. The fenites

A further group of rocks found as ejected blocks only from the volcano of Oldonyo L'Engai, consists of the contaminated varities commonly called fenite and tveitasite. Summarising the literature on these rocks, Johannsen[1] classified them as plutonic rocks with no extrusive equivalent, but qualifies this statement thus:- "the rocks are clearly hybrid and are apparently due to the impregnation of ordinary granite with aegirite from the intrusive nepheline-syenite; consequently there is some question as to the propriety of including them as types of igneous rocks". Petrogenetically these rocks are of particular interest, and it is considered relevant to quote further from Johannsen on the same subject, "where the rocks of the ijolite-melteigite series are in contact with the biotite-granite country-rocks in various places in the Fen area, in Norway, there occur rocks which are gradational between them. Some are melanocratic and some are moderately leucocratic". To the former Brögger gave the name tveitasite and to the latter the name fenite". Both of these rocks are mentioned again in the section on petrogenesis.

(1) Johannsen A. A descriptive petrography 1938. Vol.IV. p.32

In the description of the coarser grained nephelinites likened to the urtite-ijolite-meltoigite series, types were noted which were gradational towards these more hybrid rocks. Thin sections were made from five of these fenite types:- The specimen J0693 was collected whilst descending the westerly ridge of Oldonyo L'Engai after the 1930 ascent, from a point below the outcropping rock forming a ridge high up on the western flank. Another specimen, J0689 came from the same locality, and a third specimen J0907, was picked up some three miles west of the south-westerly flank of Oelai, that is, in the Oldonyo L'Engai neighbourhood. Two other specimens, J01201 and J01222 were collected at about 8,500 feet up the westerly flank of Oldonyo L'Engai after the second ascent in 1931. All are ejectamenta. Macroscopically, these rocks are most distinctive, and generally are fine grained, saccharoidal-looking rocks, with lighter white or yellow areas, and some patches and veins of darker minerals, cutting through all the other lighter coloured areas; some pyrites is present, and the rock has every appearance of being very much altered by heat, and closely resembles basement rock in contact with lava flows.

In thin section J0693(1) is reasonably typical of the fenites and shows a marked granular but certainly not equi-granular texture. Large orthoclase crystals, often containing a great number of inclusions, and of very ragged outline, are embedded in a ground mass of much smaller orthoclase grains, associated with anhedral interstitial apatite. The darker minerals are ragged plates of deep green aegirine, often occurring in clusters together with some sphene and ore which is pyrites. In the slide J0693(2) sphene is very common, and tends to occur in patches, apatite is fairly abundant and is scattered through the slide in association with the orthoclase. The slide J0689 is somewhat similar, but there are also present large dark areas, consisting of a mass of interlocking aegirine fragments with sphene. Large altered anorthoclase, and other more perthitic felspars are to be seen in the thin section of J0097. Microscopically, J01831 is similar to J0860, and J01832 is a very fine grained granular rock containing more aegirine-augite, and is gradational to the tveitasite-rock-type. No analyses were made of fenites from this area, but some analyses of fenites and tveitasites from other well know localities are given in the next section, see table No.[18].

4. The tveitåsites

Three examples of the darker tveitasites are considered here, they were collected from the following localitites:- The specimen J0864 came from near the summit of Oldonyo L'Engai whilst ascending from the inner crater to the easterly rim of the new northern crater. The specimen J0870 was collected on the westerly flank of the volcano after the 1960 ascent. The third specimen J0909 comes from a dry river course on the northern flank of Oldonyo L'Engai. All the above are ejectaments.

In the hand specimen these rocks are generally dark, compact, fine grained, green rocks, with coarser grained xenoliths of felspar, pyroxene, and some pyrites. Microscopically they resemble the fenites, except that pyroxene is far more abundant than the orthoclase. In the slide J0864 aegirine-augite is more common than aegirine, and this is generally the case in the other thin sections of the tveitasites. Sphene remains quite common, especially in J0909, which is very rich in the dark minerals, and must be gradational towards the malignites.

TABLE NO. 10

Chemical Analyses Of Fenites and Tveitasites From Other Alkaline Areas

	No.1	No.2	No.3	No.4	No.5
SiO_2	60.35	62.17	62.24	50.27	40.46
Al_2O_3	16.70	15.04	17.17	11.50	3.08
Fe_2O_3	1.09	3.20	1.28	6.12	5.97
FeO	1.05	1.05	0.82	3.81	7.45
MgO	.10	.40	0.57	2.49	5.57
CaO	4.39	3.01	2.00	9.37	18.27
Na_2O	6.24	6.23	4.45	2.08	3.03
K_2O	6.12	7.16	8.40	7.52	1.59
H_2O +	.24	.41	0.31	0.72	.44
H_2O -	.12	.02	0.20	-	.19
TiO_2	.11	.44	0.54	0.10	1.64
P_2O_5	.50	.05	0.32	0.94	2.34
MnO	.10	.11	0.06	0.38	.42
CO_2	.45	1.61	0.04	3.77	1.12
ZrO_2	.04	.08	-	-	.05
F	.03	tr	0.04	-	.20
S	.05	.00	0.33	0.15	.34
BaO	.03	.15	0.46	0.17	.06
Cl	-	-	-	-	.02
	100.23	100.21	100.02	100.02	100.22

Modes

Or. plus Naf	36.24	22.77	-	-	-	-
Ab	46.85	35.38	20.6	-	7.37	-
An	1.09	1.02	-	-	-	-
Aegirine	{7.51	{13.46	{	{18.1	-	20.6
Aegirine-augite			8.1		-	-
Sphene	.28	.77	-	-	4.03	-
Zircon	.06	.075	-	-	.07	-
Apatite	1.182	.13	0.8	2.2	5.35	1.0
Calcite	5.57	3.66	1.9	6.6	2.55	-
Magnetite	-	.23	-	6.1	tr	-
Pyrite	.05	.17	0.4	0.3	.04	-
Quartz	-	-	2.6	-	-	-
Ba-feldspar	-	-	-	-	.24	-
Orthoclase	-	-	-	-	7.60	-
Pyroxene	-	-	-	-	71.50	-
Perthitic orthoclase	-	-	66.8	-	-	-
Biotite	-	-	3.7	5.0	-	-
Ores	-	-	1.1	-	-	-
Soda-orthoclase	-	-	-	40.6	-	68.2
Pseudomorphs of plagioclase	-	-	-	10.1	-	-
Zeolite and calcite (mainly in veinlets or vugs)	-	-	-	-	-	4.2
			100.0	100.0		

No.1 Fenite. West of Holteig, Norway Rødland analyst. Brøgger: Eruptivgest. Krist. IV 1921. 158.
No.2. Fenite. Fen area. Rødland, analyst. Idem loc. cit.
No.3. Syenitic fenite. Stolpas, Alnø. analyst N.Blix. Eckermann, Alkaline District of Alnø Island. 1948 p.35.
No.4. Fenite, Alnø, analyst N.Sahlbom. Idem loc. cit p.30.
No.5. Tveitasite, Fen region. Rødland analyst. Brøgger. loc. cit. pp. 162-170.
No.6. (Mode only) Fenite. W.Usaki, Kenya, W. Pulfrey - Ijolitic rocks near Homa Bay, W.Kenya. Q.J.G.S. 1950. pp. 425-459.

The mellilite-basalts of Oldonyo L'Engai, and the southern shores of Lake Natron

The rock J0888 is representative of a large, and presumably one of the oldest lava flows from Oldonyo L'Engai; it was collected from the southern flank of this volcano, where it forms a distinct ridge. In places it can be seen overlying the more basaltic lava from Oolai, to the east. Similar rocks were collected from a small volcano called Armykon, situated to the north of Oldonyo L'Engai, by the south-east shore of Lake Natron, and another rock J0906, was collected from the southern shore of Lake Natron in the immediate neighbourhood of Armykon.

Macroscopically, these rocks are most distinctive; they are hard, compact, and often slightly vesicular, with a noticeable greasy lustre. The rock weathers to a brown ferruginous and calcareous crust, small laths, presumably mellilite and larger olivines can sometimes be distinguished.

In thin section, the Oldonyo L'Engai rock J0888, is vesicular and consists of abundant laths of mellilite showing the typical blue-grey birefringence colours under polarised light: in places the mellilite laths tend to exhibit flow texture. Fresh olivines occur as microphenocrysts, and quite a feature of this slide are the abundant octahedra of both magnetite and perovskite, the latter being red and yellow in colour, and under high power show birefringence and twinning. Secondary calcite, and some haematitic ferruginous material occurs interstitially.

Two thin sections of J0958 from Armykon Hill show a more vesicular rock containing some larger tabular mellilites, together with smaller mellilite laths, in a very fine grained ground mass: Magnetite and perovskite are common, and the chemical analysis quoted below see table No. 19 , shows 4.00% TiO_2. The ground mass consists largely of green volcanic glass with an R.I. greater than balsam. In one slice J0958(3) there is a fair amount of interstitial secondary calcite. The other rock J0906 has a very dark ferruginous ground mass, with much calcite infilling some of the larger vesicles.

The chemical analysis of JG958 when compared with what Johannsen[1] calls "the original melilite-basalt" No.1 in the table below, is seen to contain very much less MgO and Fe_2O_3 but the alkalis and TiO are higher. Another rock No.2 shows a similar amount of TiO_2, but is otherwise very different, the MgO being especially high and the CaO low when compared with JG958. The analysis from Elgon No.3 contains more silica, less alumina, and is not so rich in alkalis as JG958.

(1) Johannsen A. A descriptive petrography Vol. IV 1938. p.350.

TABLE NO.10

Chemical Analysis of Melilite-basalt 33958 From Armykon Hill On The South-eastern Shore Of Lake Natron

	J0958	No.1	No.2	No.3	No.4	No.5	No.6
SiO_2	34.46	33.80	38.87	40.30	33.04	34.72	38.73
Al_2O_3	9.18	9.93	11.94	4.04	6.34	12.10	10.78
Fe_2O_3	6.10	15.05	4.02	8.93	0.45	6.44	5.87
FeO	8.77	n.d	6.80	6.71	8.90	4.82	8.78
MgO	9.83	15.14	13.24	10.80	7.01	5.84	12.74
CaO	18.58	16.19	10.87	17.99	27.19	19.08	13.70
Na_2O	4.45	2.88	2.50	1.00	2.18	5.11	3.03
K_2O	2.52	n.d	1.64	1.54	.12	3.05	0.91
H_2O +	.63	2.90	3.82	2.60	.43	2.13	(not
H_2O -	.57			0.01	.22	.17	given)
TiO_2	4.83	.64	4.70	3.30	1.90	3.31	2.04
P_2O_5	1.25	1.41	tr	0.75	.24	1.00	1.10
MnO	.24	tr	-	0.20	.25	.28	0.12
CO_2	.82	1.41	tr	-	.30	-	
SO_3	-	.04	-	-	-	.01	(not
S	-	tr	-	-	.02	.17	given)
Cr_2O_3	-	tr	3.06	-	-	-	
SrO	-	-	-	-	.26	-	
	100.23	100.00	99.93	100.07	99.74	100.00	(97.13)

NORM of J0958

Leucite		6.08	
Nepheline		17.80	
Kaliophilite		3.48	
			28.38
Acmite		4.18	
Olivine			
$2MgO\ SiO_2$	17.22		
$2FeO\ SiO_2$	3.57	20.79	
Akermanite		25.05	
Magnetite		6.73	
Ilmenite		9.27	
Apatite		3.02	
Calcite		1.80	
			70.62
	plus H_2O		1.20
			100.37

J0958 Analyst W.H.Herdsman.
C.I.P.W. classification:- IV (1), 2 (8), 1 (3), 3 No name.
Niggli values:- si 61.50; al 9.00; fm 47.06; c 31.77; alk 10.62; k .27; mg .55; qz -77.90

No.1 Hochbohl, near Owen, Wurttemberg. Meyer analyst Stelzner. Neues Jahrb., B.B., II, 1883, 398 - mellilite-basalt.

No.2 Hohenhowen, Hegau, Baden. Grubenmann, analyst. Grubenmann: Inaug. Dissert., Zurich, 1886,31 mellilite-basalt.

No.3 Mellilite-nepheline-basalt, Mt. Elgon, analysts N.Sahlbom; Odman O.H. Volcanic rocks of Mt.Elgon, Geol. Foren; Forhand; 1930 vol.52.

No.4 Fine grained uncompahgrite, Iron Hill, Colarado. George Steiger analyst. E.S.Larsen. Geol. Surv. Prof. paper 197-A.

No.5 Average of three analyses by Eskola and Kranck of Turjaite, Turja, Fennia 51, p.33, 1928.

No.6. Mellilite-nepheline basalt; average of 6 analyses Hawaii petrographic province, G.A.Macdonald. Amer. Geol. Soc. Vol. 60, 1949 (2) p.1571.

Normative analyses

	JG958	No.3	No.4	No.5	No.6
an	-	1.11	7.23	1.39	9.17
lc	6.98	6.98	.44	13.95	4.36
ne	17.89	7.76	9.94	23.28	17.80
kp	3.48	-	-	-	-
ac	4.16	-	-	-	-
di	-	56.16	39.07	13.61	22.61
ol	20.79	1.40	1.57	5.74	19.98
ak	25.05	-	-	-	-
cs	-	6.80	23.39	17.53	7.22
mt	6.75	12.09	12.30	7.19	8.12
il	9.27	6.23	3.80	6.23	5.32
hm	-	-	-	1.44	-
ap	3.02	1.08	.07	3.70	2.69
cc	1.80	-	-	1.80	-
H_2O	1.20	-	-	-	-
	100.37	101.10			

C.I.P.W.

JG958

IV (1), 2 (5)
1 (3), 3.

No.3

IV,2,2,1,2.

No.4

IV,2 (2),3.3.2

No.5

"III, "9. 1".4.

Compared with the other analyses, J0958 shows rather high FeO, whilst the MgO tends to be low; the alkalis are lower in the other rocks except the turjaite, and Na_2O exceeds K_2O. The TiO_2 - 4.06% is the highest figure for all the five analyses and in J0958 there is more normative olivine and less normative pyroxene than is shown in the other norms. Apart from the carbonatites of Kerimasi, this rock contains the lowest silica percentage of any of the new analyses incorporated in this work on the rocks from the Oldonyo L'Engai district of Tanganyika Territory. It is interesting to note the similarities and differences between J0958 and No.C, the average analysis of six mellilite-nepheline basalts from Hawaii. In the case of J0958 the MgO is once again low, whilst CaO alkalies and TiO_2 are higher.

TABLE NO. 82 **Classification of the less common rocks from Kerimasi and Oldonyo L'Engai**

KERIMASI ONLY			Kerimasi and Oldonyo L'Engai	OLDONYO L'ENGAI ONLY				
Sovites or Carbonatites	Calcareous Tuff	Certain Rock Fragments In The Tuff		Trachyte	Urtite-Type	Fenite	Tveitasite	Melilite-Basalt
1. With Forsterite, Magnetite and some Apatite. JG810 · 2. Granular Type 1239 1247 1270 3. Cellular Type 832 835 1247 1253 4. Carbonatite with Apatite 814 823 1234 1264 1267 5. Calcite-Rich Type 1265 1266 1269 1271	1. Calcareous Tuff 824 (1) 821 825 (2) 826 (2) 2. Calcareous Tuff with Ferruginous Material 823 (1) 790 (2)(4) 1259 1252 3. Calc. Tuff Rich in Aegirine and Nepheline 811 855 1256 1261 1262 4. Calc. Tuff Rich In Mafic 759 827 1237 (1)(2) 1250 (1)(4) 1251 1263 (2)	1. Basement Types (Mamota Hill) 790 (3) 2. Older Extrusives a) Andesitic Types 790 (1) (Mamota) 810 820 b) Nepheline Melabasalt 1238 c) Altered Dolerite 1234 3. Younger Extrusives a) Porphyritic Melanite Urtite 837 b) Melanite-Biotite-Ijolite 814 (2) c) Amphibole-Micro-Melteigite 815 4. Pyroxene-amphibolite 810 (Kisetoy)	Biotite-Pyroxenite Kerimasi 1254 L'Engai 1274	837	859	858 869 907 1231 1251	864 870 909	Oldonyo L'Engai 883 Armykon Hill (S. End of L. Natron) 906 958

Further younger extrusive alkaline rocks from Oldonyo L'Engai, Kerimasi, Mosonik and Shombole

It is now proposed to describe a series of sodic-alkaline rocks, which are common to all the younger volcanoes of this area. The rocks are considered to be extrusive in origin, and are invariably fine grained. The two main groups mentioned below have oth been further subdivided into leucocratic and melanocratic members, with additional local variations. The two groups are as follows:-

Group 1 Felspathoid only present, feldspar lacking

1. Nephelinites, fine grained variety
   - (a) Leucocratic types.
   - (b) Melanocratic varieties - melanephelinites.
2. Nephelinites, coarser grained variety.
   - (a) Leucocratic urtite type.
   - (b) Nephelinities resembling ijolites.
   - (c) Melanephelinites resembling melteigites.
   - (d) Melanephelinites resembling the nephelinitic-phonolites.

Group 2 Nephelinitic-phonolites with nepheline and feldspar.

1. Nephelinitic-phonolites with phenocrysts of nepheline and feldspar.
   - (a) Leucocratic types
     - (1) Nephelinitic-phonolites.
     - (2) Nephelinitic-phonolites similar to the urtite-ijolite plutonic rocks.
   - (b) Melanocratic types
     - (1) Nephelinitic-phonolite types.
     - (2) Rocks with ijolite-melteigite affinities.
2. Nephelinitic-phonolites with phenocrysts of nepheline, but containing feldspars in the ground mass.
   - (a) Leucocratic types.
   - (b) Melanocratic types.

The second group of rocks are considered to be near to the extrusive equivalents of nepheline-syenite, and there are of course gradations between one group and another and generally between one subdivision, and another. The table shows a classification as above of thin sections and their localities.

<u>Group 1</u> <u>Felspathoid only present, feldspar lacking</u>

1. <u>Fine grained nephelinites</u>

(a) <u>Leucocratic type</u>

Microscopically, these rocks have a light coloured ground mass, are very fine grained, and consist of small euhedral nephelines with needles of aegirine-augite. Sometimes there are micro-phenocrysts of nepheline (JG831) and in the same slide, the green pyroxene shows colour zoning, being deeper green in the centre of the crystal. There are some patches of analcime in this slide, which contains remarkably little magnetite. Three other similar thin sections, JG 845, 846, 847 all contain more ore, and are gradational to the melanocratic variety. Sphene is present together with some small rounded grains, with high R.I., which appear to be isotropic, and may be garnet or perovskite; there is also some very fragmentary dark brown amphibole. In JG845, at least one large octahedron of perovskite was noted.

The rock JG831 was collected near the base of the rift wall, on a traverse working southwards from Oldonyo L'Engai to Kerimasi.

The three other rocks were found to the north of the path leading westwards to Elan Nairobi, they form a series of low hills towards Kerimasi, and are believed to represent a lava flow from Oldonyo L'Engai. The specimen JG845 was collected to the north of but nearer to the path mentioned above, whilst both JG846 and JG847 were collected from outcrops progressively further northwards.

In the hand specimen, these rocks are dark green in colour, fine grained and compact, but can have vesicular tendencies. Sporadic greasy nepheline, and rarer pyroxene are visible, and in J0881 there are some darker parallel bands in the ground mass.

(b) Melanocratic varieties - melanephelinites

An increase in the amount of aegirine-augite and ore present generally in the ground mass, is used to separate the melanocratic from the leucocratic group. Examples of this type from Mosonik are J0960 and J0983. In thin section though richer in ferromagnesian minerals they resemble the leucocratic varieties whilst in J0960 red brown perovskite is particularly abundant. The ground mass of J0983 (1) is very dark, and contains much isotropic, yellow volcanic glass, with an R.I. greater than balsam; some analcime is present, and there are also long, thin, colourless fibres, showing straight extinction which are probably wollastonite. The specimen J0960 was collected from about 125 feet below the top of the rift wall to the south-east of Mosonik; macroscopically, it is a fine grained, compact, slabby rock, dark green in colour, with some small glassy nepheline phenocrysts. The other specimen J0983 was collected from lower down the same scarp but further to the north at a point about half way between the mouth of the Malambo river, and the small hills at the base of the south-eastern flank of Mosonik.

A somewhat similar rock fragment comes from the large crater of Embagai, to the south of Kerimasi, previously shown to consist of calcareous tuff, this rock, J0774, contains abundant opaque ore in the ground mass, with small, often euhedral, dark brown, melanite. There are some euhedral nephelines present, a little aegirine, and much yellow volcanic glass; a few of the many cavities are infilled with zeolites and calcite. In the hand specimen this is a very fine grained, compact, green to grey rock.

Two other melanephelinites J0955 and J0956 are most distinctive rocks in the hand specimen and were collected from the outcropping rock behind the place where the stream of sweet water, called Ndalalani rises near the SW corner of Lake Natron. Macroscopically, J0055 shows yellow, greasy nepheline phenocrysts, embedded in a fine grained dark green matrix; and J0056 is a dark compact rock with an irregular rough surface and shows small phenocrysts of nepheline in a very fine grained, black ground mass. In thin section both these slides contain very much volcanic glass and possible sodalite was noted in J0055.

(J0970) The chemical analysis in table No.   below was made on one of the many small nepheline crystals which have weathered out of J0055, and can be collected in the Ndalalani region. The analysis is compared with a nepheline concentrate from near Homa Bay in Kenya. Both contain a fair amount of kaliophilite; 33.00% K_2O in the case of J0970.

Using the immersion method and a Leitz-Jelly refractometer, the following R.I. determinations were obtained:-

	n_ε	n_ω	$n_{\omega-\varepsilon}$
J0970	1.537	1.532	.005
Nepheline from Homa Bay - analysis quoted below	1.543	1.540	.003

TABLE NO. 21

Chemical Analysis Of Nepheline Crystal JG970

	JG970		No.1		No.1a
SiO_2	41.30		41.16		39.08
Al_2O_3	30.04		33.54		35.70
Fe_2O_3	1.47		.80		1.07
FeO	2.50		-		-
MgO	.74		.23		.30
CaO	1.04		2.64		2.93
Na_2O	13.53		12.80		11.64
K_2O	6.56		6.54		8.72
H_2O +	.47	(+80°C)	2.74	(+30°C)	.46
H_2O -	.78		-		-
TiO_2	.36		-		-
P_2O_5	.04		.33		-
MnO	.03		-		-
CO_2	tr		-		-
	99.72		100.78		99.98

JG970 Nepheline crystal melanephelinite Ndalalani
Analyst W.H.Herdsman.

No.1. Nepheline concentrate S.Usaki, Ijolite-pegmatite. Analyst W.F.Horne. W.Pulfrey Ijolitic rocks near Homa Bay, W.Kenya. Q.J.G.S. Vol. XXIII. 1950.

No.1a Composition of No.1 obtained by W.Pulfrey, by deduction of 0.76% apatite and 25% natrolite.

A more unusual type JG978 was collected from the rift wall about 1½ miles south of the mouth of the Malambo river, and contains less euhedral nepheline, and much isotropic, low R.I. analcime and some zeolite, both after nepheline, with aegirine-augite and some sphene. The hand specimen is similar to those already described in this group but the nephelines are often very decomposed especially around the crystal boundaries.

2. Coarser grained nephelinites

The majority, if not all of these rocks, are most certainly extrusive in origin, but although still fine to medium in grain size, are on the whole, coarser grained than the group of rocks just described. In many cases they are considered to resemble the urtite-ijolite-melteigite series of the plutonic rocks. The classification of these rocks was originally based by Brogger[1] and later by Johannsen[2] on the proportion of the nepheline present; melteigite, less than 50%, ijolite 50-70%, urtite more than 70%. This proposal has been adopted here as the broad basis for the classification of these extrusive nephelinites.

(a) Leucocratic urtite types are uncommon, the only possible example is JG859(a) from Oldonyo L'Engai, which has been described already see p. 88 .

There are, however, many examples of these coarser grained nephelinites resembling ijolite, which are now considered.

(b) Nephelinites resembling ijolites

These rocks consist of between 50 - 70% nepheline, as medium to large sized crystals, together with aegirine-augite, and accessory amounts of magnetite, sphene, perovskite and at times apatite.

A specimen JG872 was collected whilst descending the westerly flank of Oldonyo L'Engai, and macroscopically, is very fine grained and granular, consisting of dark pyroxene and lighter coloured nepheline grains, with small phenocrysts

(1) Brogger W.C. Eruptivgest. Krist. IV. 1921 pp.17-18.
(2) Johannsen A. Descriptive petrography IV. 1938. p.313.

of mica, and an irregular shaped aggregate of magnetite, about one inch in length. In the thin section the mica is strongly pleochroic biotite, present in corona form around a large xenocryst olivine; sphene is very common, and in one place encloses the perovskite. Another similar rock JG1278 was collected from just below the summit of Oldonyo L'Engai. It contains much interstitial anhedral, opaque, dark brown material which may be garnet and in places is in close association with some magnetite; both seem to be of late origin.

Another example from Oldonyo L'Engai is the rock fragment JG1279 also collected from near the summit of that volcano. It contains dark brown to opaque, sometimes hexagonal, garnet, and some pyrites. Similarly, there is a very good example of a xenolith of olivine, surrounded by a corona of diopside fragments biotite and magnetite, the magnetite and diopside decrease in grain size outwards towards the more normal rock consisting of aegirine-augite and nepheline. These olivine xenocrysts with coronas of biotite were noted in JG872 described above, and in JG863 to be described later. The reaction of olivine, xenocrysts in a nepheline melt, would liberate the necessary potash for the formation of the biotite, if kaliophilite is present in the nepheline. From the analysis previously given of the nepheline crystal JG970, where this is the case, it is assumed the same applies in those nephelinites where coronas are found; eventually the olivine would be replaced.

(JG1279) A chemical analysis of JG1279 is given below, see table No. 22 , where it is compared with four similar analyses, three from East Africa, one of which, JG808, is a melanocratic melanephelinite from Kerimasi described later. The rock JG1279 is noticeably richer in CaO than the melanephelinite from Napak. In these rocks, more especially the melteigite from Alnö, the TiO_2 is relatively high. The Oldonyo L'Engai rock is not quite so basic as the example from Alnö, which shows slightly less silica, much less Al_2O_3, more total iron but less MgO and more CaO, whilst alkalis are less, but TiO_2 much higher.

It resembles fairly closely the ijolite from Kenya an example of the equivalent plutonic rock type, but both JG1279 and JG808 are noticeable for their high MgO content compared with the other rocks in the table. This is not the case, however, with another melanephelinite JG1275 from Oldonyo L'Engai, which contains much less silica and is considered later, see table No. 23.

TABLE NO. 22

Chemical analyses of Melanephelinites from the Oldonyo L'Engai area

	J01270	No.1	No.2	J0808	No.3
SiO_2	43.93	43.85	42.16	46.59	41.69
Al_2O_3	13.84	14.37	8.95	10.46	14.37
Fe_2O_3	2.40	6.09	9.73	5.04	7.02
FeO	8.42	4.06	3.09	6.10	2.81
MgO	7.46	3.41	6.06	8.51	3.00
CaO	14.23	10.09	17.01	16.06	16.27
Na_2O	6.03	8.77	3.05	6.09	6.49
K_2O	2.13	3.47	1.79	1.78	2.79
H_2O +	.82	2.00	0.94	.46	2.73
H_2O −	.14	0.72	0.20	.15	.72
TiO_2	2.76	2.96	5.20	.89	2.50
P_2O_5	.61	.97	0.00	.46	.54
MnO	.44	.21	.50	.23	.18
CO_2	-	none	2.01	-	.40
F	-	-	0.05	-	-
Cl	-	.04	-	-	-
S	-	.02	0.89	-	-
BaO	-	.11	tr	-	-
SrO	-	.11	-	-	tr
Li_2O	-	-	-	-	tr
	99.86	100.33	100.65	100.23	100.66
Less O Equivalent		0.03			
		100.30			

Niggli values: J01270 si 99.69; al 16.73; fm 36.93; alk 14.50; c 31.84; k .168; mg .6275; qz - 67.51

Niggli values J6 808 si 89.82; al 12.17; fm 41.37; alk 13.36; c 33.10; k .163; mg .6068; qz - 60.05

Niggli values No.3 si 91.00; al 18.5; fm 30.00; alk 16.50; c 36.00; k .25; mg .43; qz - 71.00

	J01279	No.1	No.2	J0808	No.3
or	12.23	20.57	10.57	-	6.67
ab	1.05	6.81	11.59	-	-
an	5.00	2.78	5.56	-	8.06
lc	-	-	-	8.28	7.85
ne	26.41	25.00	7.68	23.86	23.86
nc	-	-	-	-	.53
ac	-	-	-	4.62	-
di	14.38	18.36	27.26	43.93	21.17
wo	10.02	7.66	9.29	-	14.98
ol	10.92	-	-	4.13	-
ak	-	-	-	7.07	-
mt	3.48	7.89	-	4.87	8.55
hm	-	1.60	9.73	-	5.28
il	5.32	5.78	5.45	1.07	4.71
tn	-	-	5.70	-	-
ap	1.34	2.38	-	1.34	1.24
fr	-	-	.16	-	-
pr	-	-	1.90	-	-
cc	-	-	4.59	-	.40
H_2O	.66	3.62	1.17	.61	2.78
	99.81	100.42	100.65	100.38	100.08
	III,7,2,4 Kamerunose	IV,7,1,3.(4)	IV,2,1,3,2. Brandbergose	IV,1,2,1,(2)3.	III.8.2.2. Albanose

J01279 Melanephelinite, Oldonyo L'Engai, Analyst, W.H.Herdsman.

No.1 Melanephelinite, Napak area, analyst B.C.King. B.C.King 1949, The Napak area of S.Karamoja, Uganda, Memoir V, Geol. Surv. Uganda.

No.2 Melteigite, Alnö, Analyst N.Sahlbom, von Eckermann, 1948. The Alkaline District of Alnö.

J0 898 Melanephelinite, Kerimasi, Analyst, W.H.Herdsman.

No.3 Ijolite, S.Usaki, Analyst, Miss A.F.R.Hitchens, W.Pulfrey, Ijolitic rocks near Homa Bay. Q.J.G.S. Vol. CV 1950.

Two rocks from Kerimasi fall into this group of ijolitic-nephelinites, one is JG812, and in thin section resembles the more granular types noted from Oldonyo L'Engai, and was found in a tuff at the SSE base of Kerimasi. In hand specimen it is a fine grained, compact, dark rock, rather granular and appearing to consist essentially of pyroxene and nepheline. The other rock JG1238 from the base of the southern flank of Kerimasi, resembles the fine grained nephelinites, in thin section but contains many large phenocrysts of nepheline and aegirine-augite: calcite is replacing the nepheline and there is generally a fair amount of interstitial calcite present. In the rather weathered hand specimen, there are numerous xenoliths consisting essentially of nepheline and pyroxene.

(c) Melanephelinites resembling melteigites

There are several varieties of this type of rock, which consist of aegirine-augite and nepheline, now less than 50% in quantity, with most of the accessory minerals mentioned in the rocks described above.

The rock JG873 was collected whilst descending the westerly flank of Oldonyo L'Engai. It is a granular type containing the above minerals and much sphene. The larger pyroxenes have a core of diopside, and an outher edge of deeper green aegirine-augite, the ore is pyrites. In the hand specimen it closely resembles the ijolitic-nephelinites.

Another Oldonyo L'Engai rock JG884, collected in a dry water course on the east flank of Oldonyo L'Engai, is different, with apatite as the predominant light mineral: it also contains some haematite and pyrites, and possibly opaque garnet. Red brown perovskite is common in the slide JG1274(3), which is also apatite-rich: it was found as an ejected block on the summit of the volcano, and is probably a product of the last eruption, 1940-41. Another rock collected from just below the summit of Oldonyo L'Engai, contains distinct, brown commonly anhedral garnet in the thin sections JG1270(1)(2). In yet another rock collected from near the summit of the same volcano, the laths of the aegirine-augite are frequently aligned showing rudimentary flow texture.

There are several other rock-types, nearly all collected from the summit region of Oldonyo L'Engai, which are worthy of note under the same heading. One of these JG1277 contains microscopically, much dark interstitial, and generally anhedral garnet, associated with pyrites: aegirine-augite predominates and is frequently both twinned and zoned.

A second unusual and uncommon type JG865 was collected from the eastern rim of the new northern crater of Oldonyo L'Engai, and is a most distinctive rock in the hand specimen. In common with the other ijolitic-meltegite types, it is fine grained, and granular but contains books of mica 2 inches in length, and phenocrysts of amber-coloured olivine, embedded in a ground mass mixture of pyroxene and feldspar. Microscopically, besides the typical minerals mentioned above, brown biotite mica is present and is strongly pleochroic from a very dark brown to paler reddish brown colour, the extinction is straight, and by U-stage the 2V measurements ranged from 27° to 36½°. Sphene is abundant in places. This rock appears to resemble similar types with olivine xenocrysts surrounded by biotite, as seen in JG1279 already described from the summit of Oldonyo L'Engai, and in JG872 collected as descending the westerly flank of Oldonyo L'Engai, also described above.

A third rather unusual and uncommon type is JG875, collected whilst descending the westerly flank of Oldonyo L'Engai, it is equally distinctive in the hand specimen and consists of needles of black pyroxene, often well aligned and associated with white, glassy, rather fibrous wollastonite, and interstitial greasy, pale yellow nepheline; much pyrites is present. In thin section the rock shows distinct lineation and consists of laths of aegirine-augite, and fibrous wollastonite; pyrites and some dark brown garnet tend to grow across the lineation. A little apatite is present, and rather granular nepheline. If the rock is plutonic it would be called a wollastonite-melteigite, but as it is considered to be extrusive, and is fine grained it is perhaps more correctly called a wollastonite-melanephelinite.

Similar rocks to those described above from Oldonyo L'Engai in this section, have been noted from other localities. For instance, from the south-east ridge at the base of Kerimasi, the rock JG808 was collected as a fragment in a tuff. In the hand specimen it is similar to the examples from Odonyo L'Engai, being dark in colour, and granular, with small fairly abundant phenocrysts of mica. Microscopically, it consists of large plates of aegirine-augite, the centres of which poikilitically enclose nepheline and magnetite and some apatite: there is a distinct lineation visible in thin section.

A chemical analysis has been made of JG808, and is compared with JG1279 and three other similar rocks in table No. 22. The rock from Oldonyo L'Engai JG1279 is a more leucocratic melanephelinite type, but has points in common with this melanocratic variety from Kerimasi. The MgO in both rocks is high, but JG808 has more silica, much less alumina, more iron, MgO and CaO, whilst K_2O is a little lower and TiO_2 is appreciably less. The low TiO_2 and high MgO are rather unusual features, although the high MgO tendency has been noticed in other rocks from this particular province. The analysis should also be compared with that of JG1275 a more basic melanephelinite, from Oldonyo L'Engai, details of which will be found in table No. 23 .

Another rock fragment JG1202 was collected from a tuff in a river section on the SE flank of Kerimasi, and is interesting, as it consists largely of a mass of small interlocking, deep green, aegirine-augite plates, with interstitial, yellow coloured areas, believed to be analcime;

sphene is present, and possibly some rare nepheline.

Rather like the finer grained melanephelinites, is JG940, from the small hills in the south-west corner of Lake Natron. It contains deeply pleochroic dark brown to pale brown mica, and is similar to JG813 from the base of the SSE flank of Kerimasi. Some of the mica-rich areas surround colourless diopside, whereas outside these areas, green aegirine-augite predominates. Mica flakes are present as phenocrysts in the dark, granular ground mass of the hand specimen. This rock resembles JG1279 and JG872 already described above.

Returning to the summit of Oldonyo L'Engai, another rock JG1275 is also considered to be a variety of the melanephelinites. It is dark in colour due rather to the amount of opaque material present than to an increase in the aegirine-augite content. A large mass of magnetite is seen and the remainder of the slide is particularly rich in a dark. brown, euhedral, almost opaque, melanite garnet, and a little wollastonite was noted.

A chemical analysis of JG1275 is given below, the analyst, Mr.R.O.Roberts M.Sc., F.R.I.C., of the Colonial Geological Surveys, Mineral Resources Division, London, reports that the original rock consisting of ore and silicate minerals, was separated by a hand magnet into a magnetic portion, which appeared to be mainly magnetite, with 0.96% MnO, and a non-magnetic portion, which was analysed with the following result:-

TABLE NO. 25

Chemical analysis of melanephelinite J01278 - non-magnetic portion-
from the summit of Oldonyo L'Engai

	J01278	No.1	No.2	No.3	No.4	No.5	No.6
SiO_2	37.13	41.21	41.69	39.20	38.69	40.04	36.01
Al_2O_3	12.11	10.67	14.57	15.75	12.69	10.88	13.05
Fe_2O_3	7.25	6.86	7.02	4.08	7.40	4.18	6.09
FeO	3.45	4.11	2.81	3.14	2.96	4.18	3.09
MgO	4.27	9.30	3.90	3.62	5.01	6.47	3.08
CaO	19.34	16.08	15.27	16.60	18.65	19.91	20.88
Na_2O	6.15	1.07	5.49	7.50	4.90	4.75	2.80
K_2O	2.54	0.93	2.79	3.05	2.19	1.80	2.31
H_2O +	0.26	5.20	2.78	.04	.70	.14	2.21
H_2O -	0.12	0.34	0.72		.36	.27	-
TiO_2	5.92	1.14	2.30	1.66	2.45	2.24	1.08
P_2O_5	2.82	0.74	0.54	3.28	1.78	1.91	3.26
MnO	.20	0.18	0.18	n.d.	.16	.28	0.44
CO_2	-	0.09	0.40	-	.66	2.08	1.01
Cl	-	tr	-	-	-	.05	-
S	-	none	-	-	.60	-	0.38
SO_3	-	-	-	-	.25	.05	-
BaO	-	0.14	none	-	-	.11	-
SrO	-	0.15	tr	-	-	-	-
Li_2O	-	-	tr	-	-	-	-
ZrO_2	-	-	-	-	.02	.10	-
F	-	-	-	-	-	.12	-
	99.54	100.07	100.08	99.66	99.75	99.90	100.16

J01278 Niggli-values: si 73.69; al 14.17; fm 29.76; c 41.07
alk 15.00; k .2143; mg .4201; qz - 83.82.

NORMS

Na_2CO_3	-	-	.53			
ab	0.00	1.05	-	-	-	-
or	10.01	5.56	6.67	-	-	3.90
an	-	17.51	8.06	6.39	1.95	16.35
lc	3.92	-	7.85	10.03	8.72	7.85
ne	26.13	8.24	23.80	22.44	21.78	13.07
ac	3.23	-	-	-	-	-
di	-	45.36	21.17	27.00	36.72	16.45
wo	-	-	14.96	1.86	10.67	14.40
ol	7.40	1.03	-	-	-	-
ak	20.00	-	-	-	-	-
cs	-	-	-	12.10	-	-
mt	.46	10.67	2.53	2.78	6.03	6.72
il	7.45	2.13	4.71	4.71	4.26	2.09
hm	5.92	1.28	3.20	5.60	-	3.52
pr	-	-	-	-	-	-
ap	6.72	1.68	1.24	4.37	4.37	7.13
pf	-	-	-	-	-	3.69
cc	-	0.20	0.40	-	4.70	3.69
tn	-	-	-	-	-	-
	99.41					
plus H_2O	.38	5.54	2.78			2.21
	99.79	100.90	100.06			100.19
C.I.P.W. Classification	III.1.6. 1.4.	IV.2.1. 3.2.	III.8.2.2 Albanose	III (IV)2 8(2),(2)1 2.4.	IV.2.2.	III.7.3.4 Etindose

No.1 Olivine-melanephelinite K 08 from the Napak area, Uganda, Analyst B.C.King. Geol. Surv. of Uganda. Memoir V. 1949.

No.2 Ijolite from southern Ugaki, Kenya, Analyst Miss A.F.H.Hitchens. W.Pulfrey, The ijolitic rocks of Homa Bay. Q.J.G.S. Vol. CV.

No.3 Melanite-melteigite, Kerimasi. Analyst Lyme. Brögger W.C. Die Eruptivgest. Krist. 1921 IV. p.40.

No. 4 Melteigite, North Beaver Creek. Uncompahgre quadrangle, Colo; Analyst Steiger. Clark: U.S.G.S. Bull 591, 1915, 155.

No.5 Melteigite, Melteig, Fengebit, Norway. A Rodland Analyst. Brögger W.C. Die Eruptivgesteine etc. Vol. IV. 1921.

No.6 Melanite-melteigite, Alnö, Analyst N. Sahlbom. Eckermann, The Alkaline District of Alnö. 1948.

The analysis of JG1275 compares reasonably well with the other analyses quoted, which have been selected from plutonic ijolite-melteigite rock types, three of them from the East African area. The rock JG1275 is more basic than JG1279 and JG808, both melanephelinites; whose analyses are shown in table No. 22 , and have been previously discussed.

Included in this group of coarser grained melanephelinites, are other varieties with distinct affinities towards the fine-grained melanopheninites, and the nephelinitic-phonolites, and are obviously gradational towards them.

(d) Melanephelinites resembling nephelinitic-phonolites

The nephelinitic-phonolite group of rocks are described in detail below.

The least decomposed of these rocks, is JG773 from the Embagai crater, and JG949 from 2 miles south of Armykon hill, on the south-west shore of Lake Natron. They have very large nepheline phenocrysts, and much yellow volcanic glass in the ground mass. Another specimen JG950, again from a small hill about 2 miles south of Armykon hill, contains distinctive nepheline phenocrysts, zoned by inclusions, and some dark, zoned, melanite. The rock JG1163 was collected from the west flank of Shombole; the euhedral nepheline phenocrysts have in this case, undergone some decomposition. This type grades into the very much more altered types, containing the same minerals noted above, but are particularly rich in ferruginous dust and decomposition material, and they have inevitably a very dark, dense, ground mass, in which aegirine-augite appears to remain the least decomposed mineral. Macroscopically, JG1163 is a dark, compact rock, showing some small glassy nephelines and black pyroxene, situated in a dark green ground mass. Examples of this more weathered, highly ferruginous variety are, JG958 from a small hill about 1½ miles south-east of the Ndalalani stream and two similar rocks from the west flank of Shombole, JG1165 and JG1160.

Group 2 Rocks containing both feldspathoid and feldspar

If they are plutonic types, most of these rocks would be classified as nepheline-syenites, and would therefore fall into the textural classification of ditroite, foyaite or laurdalite; or other varieties based on the kind of feldspar present, such as covite and juvite; or perhaps on varities dependent on the predominant mafic mineral present, when it is the usual practise to add the name of the mafic mineral concerned to the general term nepheline-syenite, as biotite-nepheline-syenite.

However, as the rocks from this volcanic area must be considered extrusive, and invariably are of fine grain size, they are called nephelinitic-phonolites, the extrusive equivalent of the felspathoidal-rich nepheline-syenite group. They have been divided into two types, which have both been further subdivided into leucocratic and melanocratic varieties. The two types are:-

Group 2

1. Nephelinitic-phonolites with phenocrysts of nepheline and feldspar

(a) Leucocratic types

(1) Nephelinitic-phonolites.

(2) Nephelinitic-phonolites similar to the urtite-ijolite plutonic rocks.

(b) Melanocratic types

(1) Nephelinitic-phonolite types.

(2) Rocks with ijolite-melteigite affinities.

2. Nephelinitic-phonolites with phenocrysts of nepheline but containing feldspars only in the ground mass.

(a) Leucocratic types.

(b) Melanocratic types.

Several of these rocks bear a resemblance to some of the older extrusive phonolites, which generally differ from the younger phonolitic types in having strong trachytic affinities, as on Gelai and at Kibangaini.

1. Nephelinitic-phonolites with both nepheline and feldspar phenocrysts

(a) Leucocratic type

(1) Nephelinitic-phonolites

Rocks showing large crystals of potash feldspar and smaller rarer plagioclase, amongst the phenocrysts of nepheline, have been noticed from Oldonyo L'Engai, examples are JG838, JG893 and JG894. The rock JG838 was collected from a large outcrop of lava on the south-east flank of the volcano, while the other two rocks JG893 and JG894 were not found in situ, but collected in a dry water course on the east flank of Oldonyo L'Engai.

In thin section these rocks show abundant large nepheline crystals often very well zoned together with prismatic laths of sanidine and orthoclase. Aegirine-augite is present, some sphene and a little magnetite were also noted.

In the thin section of JG838 there are some large orthoclase phenocrysts with the nepheline, and feldspar microlites are common in the ground mass with small nephelines. The two rocks JG893 and 894 are similar; in the former there are abundant large phenocrysts of orthoclase, and sphene is common. In both of these rocks the ground mass is seen to be very fine grained in thin section. Macroscopically JG894 is distinctive, with abundant phenocrysts of sanidine in a black, fine grained ground mass.

A chemical analysis of JG894 is given later see table No.24 together with an analysis of JG866, a melanocratic variety in this same group of rocks. The analysis of JG894 is interesting as it contains more silica than any other new or known analysis of these younger alkaline lavas from the Oldonyo L'Engai region. The rock JG894 contains a little more silica than the nepheline-syenite from Mount Kenya, which it otherwise closely resembles; it is certainly one of the more phonolitic and less nephelinitic types of which JG866, described later is a typical example.

Three rocks from Mosonik show untwinned feldspar, they are, JG984, from the northern foot of the mountain, JG964 from near the south-west peak of Mosonik, and JG907 from the south-west flank of Mosonik. In the hand specimen all three rocks are dark, compact and fine grained, showing small glassy crystals of nepheline or feldspar, and dark needles of pyroxene. Microscopically, in JG984, the phenocrysts of untwinned feldspar have the typical large axial angle of orthoclase; the aegirine and aegirine-augite remain the common mafics and the ground mass is very fine grained, consisting of common nepheline and needles of green pyroxene, with some granular feldspar, secondary calcite, and a little magnetite. The two other specimens from Mosonik are similar, JG907 contains many small octahedra of magnetite, and much pale-green pyroxene; rather like JG964, it tends to be non-porphyritic.

Two similar rocks were collected from the Oldonyo L'Engai area, one of these, JG834 comes from a ridge about one mile south-east of Oldonyo L'Engai. Microscopically it is seen to contain phenocrysts of orthoclase with well zoned aegirine-augite, generally with paler coloured cores of diopside, some euhedral sphene is present which at times shows twinning, and is often relatively large in size: there is some interstitial calcite. In the hand specimen this is a dark, compact rock, with glassy phenocrysts of feldspar and nepheline and some pyroxene situated in a dark grey green, fine grained ground mass. The other example from Oldonyo L'Engai, was collected from a small hill immediately to the south of the small volcano called Lalarasi see fig. 1 . This rock JG836, contains melanite, and a xenolith of tveitasite rock, consisting essentially of interlocking laths of aegirine-augite, whilst another xenolith consists of small melanite, altered nepheline and granular aegirine-augite. These xenoliths together with the other common constituents of this type of rock, are all embedded in a dark ferruginous ground mass.

1. (a) (2) Rocks similar to the urtite-ijolite plutonic types

The rocks in this subdivision are more granular in texture. There are examples from Oldonyo L'Engai, Kerimasi and Mosonik.

The rock JG965(3) was collected about 500 feet below the summit of Mosonik on the south-west flank of that mountain. Macroscopically it is a fine to medium grained rock, with granular texture, it contains clear glassy grains, dark pyroxene, and a little yellow sphene. Under the microscope, like the rocks previously described, it consists of large orthoclase and nepheline crystals which tend to be anhedral.

Deep green aegirine and aegirine-augite is present with fragmentary dark brown to black biotite, conspicuous with a dark margin of ore; sphene and a little magnetite were also noticed.

Pyrites was found in JG876 collected whilst descending the westerly flank of Oldonyo L'Engai. In thin section the rock is seen to be allied to the fenites, and contains granular orthoclase and nepheline, and deep green aegirine with ragged outer margins, which often encloses poikilitically, the other minerals in the rock. In the hand specimen it is a granular, rather friable rock, with a mottled appearance, and consists of much white feldspar or feldspathoid, pyroxene, and a fair amount of pyrites.

There are two other more granular types from Kerimasi, JG1240 and JG1273 which are of interest. The former was collected from the base of the southern flank, and the latter from a dry river course on the east side of this volcano, a little to the east of Kisetey hill. Both rocks resemble the coarser grained nephelinites but orthoclase is present; some apatite was noted with dark brown to opaque garnet and abundant small anhedral perovskite. Macroscopically, these rocks are granular and fine grained, consisting of clear glassy minerals, and dark, massive, pyroxene; both rocks have a greasy appearance.

1. (b) Nephelinitic-phonolites with phenocrysts of nepheline, and feldspar - melanocratic type

The important difference between these rocks, and the specimens just described is that in this group, the rocks have a much darker appearance, especially in the ground mass material. There are two rock types in this melanocratic group, the first contains the more normal phonolitic varieties of which there are many examples from Oldonyo L'Engai, though some rocks from Shombole and other localities have similar tendencies. The second division consists of the more granular varieties, which resemble the nephelinites with ijolite-melteigite affinities, but contain feldspar; all rocks in this division come from Kerimasi and are discussed later.

1. (b) (1) Melanocratic nephelinitic-phonolites

One of the fresher looking specimens belonging to the first division, is JG863 which forms the outcropping rock at just below 9,000 feet on the western side of Oldonyo L'Engai, where it is overlain by ash.

In the hand specimen, it is a compact, green rock, showing small nephelines and feldspars with pyroxene, in a very fine grained ground mass; it probably represents the youngest lava flow from this volcano, not taking into account some of the parasitic cones at the base of the mountain. Microscopically, it consists of fresh, euhedral, zoned nepheline, some orthoclase and deep-green strongly zoned, aegirine-augite. In the very fine grained ferruginous ground mass there are smaller laths of orthoclase, commonly showing carlsbad twinning and some interstitial calcite, zeolite, sphene, and pyrites. A chemical analysis of this rock is given in table No. 24 .

TABLE NO. 24

Chemical Analyses of a Nephelinitic-phonolite JG866 and a Phonolite JG894 both from Oldonyo L'Engai

	JG866	No.1	No.2	No.3	No.4	No.5	No.6	JG894
SiO_2	48.87	48.04	47.52	47.68	53.44	53.98	51.64	53.35
Al_2O_3	18.83	19.60	18.10	17.08	20.30	19.43	19.12	19.90
Fe_2O_3	4.28	4.11	5.98	3.45	4.22	4.39	3.03	3.29
FeO	2.97	3.64	3.17	5.26	1.76	2.05	4.20	2.37
MnO	.03	1.44	1.01	2.90	1.12	1.07	1.29	.79
ZnO	6.44	6.09	7.42	7.17	2.13	2.04	2.94	3.13
Na_2O	9.36	6.48	8.11	6.33	8.76	8.81	9.40	9.48
K_2O	5.80	6.52	3.84	6.45	5.75	6.27	4.37	4.46
H_2O +	1.83	3.76	3.63	.37	.07	.85	1.63	1.06
H_2O-	1.08	-	1.25	.24		3.64	0.39	.52
TiO_2	.04	1.41	1.92	2.64	0.69	0.57	1.88	.07
P_2O_5	.23	0.17	.63	.77	.49	.30	0.33	.03
MnO	.18	0.10	n.d	.14	tr	.26	0.19	.42
CO_2	2.02	-	-	.02	-	-	-	tr
ZrO_2	-	-	-	-	0.27	-	-	-
SO_3	-	-	-	-	.22	-	-	-
Cl	-	-	-	.14	-	-	0.09	-
F	-	-	-	.08	-	-	-	-
S	-	-	-	.01	-	-	-	-
V_2O_3	-	-	-	.03	-	-	-	-
BaO	-	-	-	.28	-	-	-	-
SrO	-	-	-	.10	-	-	-	-
Li_2O	-	-	-	tr	-	-	-	-
	100.01	100.31	100.25	99.98	100.21	99.96	100.20	99.67
Less O				.06				
				99.92				
NORM								
or	22.00	38.30	-	36.56	-	31.14	27.8	26.09
ab	21.48	3.14	-	-	-	26.46	55.6	27.25
an	-	5.00	-	4.23	-	-	7.7	-
lc	-	-	-	1.22	-	-	-	-
ne	20.12	27.33	-	23.86	-	25.71	16.2	27.26
hl	-	-	-	.23	-	-	-	-
ac	6.08	-	-	-	-	3.70	-	2.31
di	7.39	9.76	-	20.08	-	6.64	1.8	5.10
wo	1.74	3.02	-	.32	-	-	-	3.48
ol	-	-	-	-	-	0.14	1.6	.63
mt	3.71	6.03	-	5.00	-	4.64	4.5	3.71
hm	-	-	-	-	-	-	1.8	-
il	1.22	2.74	-	4.82	-	1.06	1.9	1.82
pr	-	-	-	.02	-	-	-	-
fr	-	-	-	.03	-	-	-	-
ap	.34	.34	-	1.82	-	0.67	1.0	.40
cc	4.50	-	-	0.04	-	-	-	-
	96.38	96.22						98.65
H_2O	3.53	3.75		0.61				1.58
	99.83	99.97		99.70				100.23
C.I.P.W.	II.(1)7.1.4. Lujavrose	II.6.1.3. Judi-those		II.7.1.3. Janei-rose		"II.6.1.4.	II(6)7.1.4.	II.6.1.4.

Analysts

JG866 & JG894 - W.H.Herdsman
No.1 - N.Sahlbom
No.2 - F.Raoult
No.3 - H.F.Harwood
No.4 - Dr.Klüss
No.5 - G.T.Prior
No.6 - F.Raoult

Mode

	JG866	JG866	No.2	JG894	
	Range	Av.		Range	Av.
Nepheline	19.76 - 38.86	30.03	27	1.07 - 3.72	2.01
Aeg-augite	6.84 - 20.87	12.03		24.02 - 38.66	32.33
Orthoclase	.95 - 13.03	6.26		13.17 - 48.32	25.01
Sphene	0.00 - 6.04	1.83		.10 - 9.24	2.77
Fine grained groundmass, ore, calcite, nepheline.	24.83 - 41.98	33.20		25.48 - 44.33	36.90
Chlorite	.52 - 3.79	2.22			
Zeolite	.01 - 10.17	5.07			
Calcite	0.00 - 12.14	7.19			
Ilmenite	0.00 - 3.93	.79			
Sodalite (?)	0.00 - 2.13	.69			
		99.97			100.02
Sanidine			22		
Apatite			tr		
Pyroxene			44		
Olivine			7		
Magnetite			tr		

JG866 & JG894 Five Traverses over one Thin Section

No.1 Phonolite, Cortex, Mt.Elgon, Odman O.H. Geol. Fören. Förhan. Vol. 52 1930.

No.2 Murtite, Cape Muri, Rarotonga, Cook Islands. Lacroix. Mem. Acad. Sci. France LIX.Pt.2. 1927, 32. Mode calculated by Tröger.

No.3 Leucitite (Mikenite). Mikeno, Holmes & Harwood. The Petrology of the volcanic area of Bufumbira. Geol. Surv. Uganda. Memoir III. part.2.

No.4 Leucit-rhomp-porphyry from NE Kibo, 5000 m. Finckh, Die rhomben-porphyry des Kilimandscharo, Festschrift, Rosenbush, 1906.

No.5. Kenyte. Central core Mt.Kenya. Gregory J.W. 1900 Q.J.G.S. Vol. lvi. p.205-22.

No.6. Nepheline-syenite. Mt. Kenya. Gregory J.W. 1900 Q.J.G.S. vol. lvi. p.205-22.

Niggli values

JG866 - si 141; al 32; fm 19; c 17; alk 33; ti - ; k .21; mg .22; qz - 88

No.5 - si 165; al 35; fm 21; c 7; alk 37; ti 1.3; k .20; mg .23; c/fm .32; qz -77

No.6 - si 150; al 33; fm 33; c 9; alk 35; ti 3.5; k .23; mg .24; c/fm .40 qz - 84

JG894 - si 161; al 35; fm 18; c 10; alk 36; k .31; mg .20; qz - 83

In 1938 Johannsen[1] remarked (p.288) that nephelinite-phonolites, "undoubtedly are not uncommon, and it is only because so few phonolite modes have been determined that no example of the mode of an extrusive of this composition can be cited", and later (p.293) he notes that, "the melanocratic felspathoid-rich phonolites are represented in the literature by very few examples, all of which carry olivine" - those with nepheline as the feldspathoid are called murite, and an analysis of this rock is given for comparison purposes.

As their name implies, these nephelinitic-phonolites contain more silica than the nephelinites, but less silica than the phonolites; examples of both types are quoted with the analyses above. Alkalies are generally higher when compared with the less siliceous rocks previously examined, and CaO and MgO are consequently much lower.

TABLE NO.25

		JG866	JG894	No.6	No.5	No.4	No.1	No.3
From chemical analysis		Ol. L	'Engai	Mt.	Kenya	Kibo	Elgon	Bufumbira
Na_2O %		9.30	9.40	9.46	8.81	8.76	6.48	5.33
K_2O %		3.83	4.46	4.37	5.27	5.75	6.52	6.45
Expressed as % of total alk.	Na_2O	69.08	68.00	68.39	62.61	60.37	49.85	45.24
	K_2O	30.92	32.00	31.61	37.39	39.63	50.15	54.76

The predominance of Na_2O in these Oldonyo L'Engai rocks is well illustrated by a comparison of the Na_2O and K_2O ratio with some of the other volcanic regions of East Africa. Compared with the soda-rich rock JG866 another of the rocks from Oldonyo L'Engai JG894, shows a decrease in the Na_2O to K_2O ratio, which is of a similar order as that of the nepheline-syenite from Mt. Kenya. The Kenyte from Mt. Kenya however shows a slight increase in K_2O, an increase which is

(1) Johannsen A. Descriptive petrography of igneous rocks 1938 IV.

maintained in the rhomb-porphyry with leucite from Kibo, Kilimanjaro. Even in this rock, however, the ratio of Na_2O to K_2O is still only 1 to .63 very much greater than in Odman's phonolite from Elgon, where K_2O is in slight excess, or the leucitite from the Bufumbira volcanic area of Uganda, where K_2O is well in excess of Na_2O.

Nevertheless, from the evidence of the above analyses, the rocks of Oldonyo L'Engai have a relatively higher soda content than the leucitite type from the Bufumbira region, has of potash. One of Richards[(1)] rocks from Oldonyo L'Engai - 111 - shows an even greater alkali content Na_2O 14.24%. K_2O 5.19%= 19.43%. With K_2O as much as 37% of the total alkalis.

The rock JG889 was collected in the dry river course between Kerimasi and Oldonyo L'Engai and was no found in situ. It contains phenocrysts of carlsbad twinned orthoclase, and much calcitic material in the ground mass. Orthoclase with dark brown melanite was noted in the thin section of JG883, also collected from the same dry river course as JG889, the former contains a fair amount of calcite and zeolite in the ground mass. These rocks in the hand specimen are compact, green or grey in colour, often with small visible greasy nepheline, and darker pyroxene. Some other rather similar types from Oldonyo L'Engai are JG895, JG902 and JG905. The specimen JG895 was collected from the ENE flank of Oldonyo L'Engai; JG902 from near the west flank of Gelai, and JG905 from a river entering the south end of Lake Natron. The specimen JG769 was collected from the south-west flank of Kerimasi, very close to the base of the rift wall and also belongs to the above group of rocks.

Another variety JG843 (2) also from the same dry river course between Kerimasi and Oldonyo L'Engai, shows abundant, greasy, yellow, nepheline crystals in the hand specimen; at times this nepheline can be seen to include darker needles of

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(1) RichardJ.J. 1942 Volcanological observations in East Africa- Oldonyo L'Engai. The 1940-41 eruption. Journ.E.African Nat. Hist.Soc. Vol. XVI. No. 2 & 3 (71 & 72) pp.89-108.

pyroxene which are situated in a fine grained, compact, green to grey ground mass. In thin section the ground mass is seen to consist largely of green volcanic glass, with an R.I. greater than balsam. Both macro- and micro-scopically the specimen JG892 is somewhat similar, and comes from a dry river course, on the east flank of Oldonyo L'Engai, as does JG891, which with JG1104 from the western flank of Shombole are two examples of more altered types.

1. (b) (2) Melanephelinites with ijolite-melteigite affinities

In this division of the more granular rocks with both felspathoid and feldspar, there is a strong similarity to the melanephelinites. Microscopically, granular nepheline and orthoclase occurs with rather granular and generally fragmentary aegirine-augite; other accessory minerals, sphene, magnetite and haematite were noted in JG1248 (1) (2) and (3), which were collected near the base of the ridge on the south-east flank of Kerimasi. Another rock from the south-east flank of Kerimasi JG1260, has a ground mass consisting mostly of a mineral resembling analcime; whilst some orthoclase, nepheline, aegirine-augite, and sphene are relatively common. The mineral association already noted in several slides described above, of coronas of biotite, magnetite, and diopside around olivine also occurs in JG788 collected from the base of the southern flank of Kerimasi; sometimes the olivine xenocryst has been completely resorbed. Macroscopically, the rather weathered specimen contains phenocrysts of mica, and dark pyroxene, in a very fine grained, granular, ground mass of both the light and dark minerals, pyroxene and nepheline.

2. Nephelinitic-phonolites with phenocrysts of nepheline but containing feldspars only in the ground mass

There are only four rocks in this division, and three of these come from Mosonik. The specimen JG965 collected about 500 feet below the south-west summit of Mosonik is a xenolith from the lava JG966. Both rocks are themselves very fine grained and non-porphyritic; fragments of feldspar can be detected in the thin section, including some perthite in the slide JG965(2). Macroscopically, JG966 is a very fine grained slabby, green-grey rock, with a saccharoidal appearance; rare black pyroxene and altered nepheline or feldspar can be seen. Under the microscope JG966 shows some banding, and there are coronas of aegirine-augite surrounding a core of dark brown biotite associated with much magnetite: small square shaped nephelines are relatively common.

The third rock from Mosonik included in this group, is JG968, which is coarser grained, and was collected from the south-west flank of the mountain. A similar, but very altered rock from Shombolo is JG1169, which contains much calcareous material and some large altered nephelines with small laths of feldspar in a ferruginous ground mass. In the hand specimen there are many xenoliths of coarser grained rock incorporated in the normal finer grained, green to grey coloured lava.

TABLE NO.26

Classification of the Nephelinites and Nephelinitic-phonolites

	NEPHELINITES							NEPHELINITIC-PHONOLITES					
	Fine Grained		Coarser Grained					With Feldspar Phenocrysts				No Feldspar Phenocrysts	
			Leucocratic		Melanocratic			Leucocratic		Melanocratic			
	Leucocratic	Melanocratic	Nephelinitic	Types Resembling Urtite	Types Resembling Ijolite	Nephelinitic	Melano-nephelinite Melteigite	Nephelinitic Phonolites	Types Resembling Urtite-Ijolite	Nephelinitic Phonolites	Types Resembling Melteigites	Leuco	Melano
OLDONYO L'ENGAI	845 846 847 ? 881	845 847 ?		859	848(2) 872(olivine biotite) 1278 1279		865(olivine biotite) 873(1) 873(2) 875 884(apatite) 1274(apatite) 1275 1276(1) 1276(2) 1277	834 836 838 868 892 893 894 912	876	848(1) 848(2) 866 868(4) 883 885 889(1) 889(2) 902 905(1) 905(2) 1280			
KERIMASI					812 1235		803 813 1262		1240 1273		780 1248 1250		
MOSONIK		960(1) 960(2) 963(1) 963(2)					968	964 967 964(1) 964(2)	965(3)			965(2) 966(1) 966(2)	968 ?
SHOMBOLE						1163 1165 1166(1) 1166(2)				1164			1169
EMBAGAI		774(1) 774(2)				773				769			
MISC.		978 956(1) 956(2) 955				949 950 952(1) 952(2)	948(biotite) 951						

LAKE NATRON

Introduction

Many of the early German Expeditions to the Oldonyo L'Engai area, the Germans were among the first to visit this part of Africa, visited Lake Natron, and recorded some details concerning the lake. In fact, before the turn of the century an important north-south trade route seems to have been situated on the western shore.

One of the earliest of these explorers, to quote an example, was Dr.G.A.Fischer(1) who noted and recorded a hot spring with a temperature of 50°C in the Oldonyo Sambu region on the northwest shore of L.Natron. In 1904 the Anglo-German Boundary Commission mapped the north end of the Lake, and later in 1907, C.Uhlig(2) to whom we are indebted for a topographical map of this region, said of Lake Natron, "It usually contains very little water, but such as it has is rich in sodium-carbonate". His description in this work refers more to the morphology of the volcanoes and rift faulting than to the lake itself, although Dr.Scholz(3) who examined the lake in 1912, reports that Uhlig estimated 72 million tons gross of salts available in Lake Natron.

Dr.Scholz's report, which appears to have been the first real attempt to examined the lake with a view to estimating its commercial possibilities, stressed the fact that at that time, 1912, Lake Magadi in Kenya, less than 20 miles to the north, was already being worked for salts. Having examined both lakes, Dr.Scholz concluded that the amount of raw salts was higher at Lake Natron although the quality of the natural salts at Lake Magadi was superior. Common Salt (NaCl) and Glaubers Salt ($Na_2SO_4 10H_2O$) as well as other impurities are only found in small quantities in the sodium carbonate at

(1) Fischer G.A. Bericht Reise im Massailand 1882/83. Mitt.d. Geogr.Ges.Hamburg. pp.35-87.
(2) Uhlig C. Die sogenannte Grosse Ost. Afrik. Graben Geogr.Z. Vol. 13. 1907.
(3) Dr.Scholz. Report on the British and German Soda lakes. File No. GR20 of Dept. of Geol. Survey, Dodoma, Tanganyika Territory.

Lake Magadi, while they amount to 30% in the salts of Lake Natron.

On most accounts, however, the two lakes are remarkably similar, and the geological history of one resembles that of the other, although it is doubtful whether enough work has been done at either lake, to enable anything but a tentative correlation to be attempted at this stage.

Towards the end of 1929 and during January of 1930, a further examination of the deposits of Lake Natron as a source of soda was undertaken by the Magadi Soda Company. Some of the results of this very short expedition have been made available to the Geological Survey Department of Tanganyika Territory.

In 1932 J.A.Stevens[1] states that a further enquiry was made into the possibility of using L. Natron as a supply of salt, but once again, nothing developed, except, in 1933 a salt industry was started at L. Magadi.

During 1949 Guest having reached the north end of the lake via the east side of Ketumbaine started mapping and collecting - in 1929 the Magai expedition had failed to get through to the lake by this route due to terrain and thick bush. In 1950 the writer accompanied a chemist, J.A.Stevens, and spent a further two months in collecting material from the lake which led to the/publication of a joint report in 1951[1] on some of their findings, and to a further report by Guest[2] on the magnesite deposits of Gelai. Also in 1950, Dr.B.H.Temperley and A.O.Thompson[3] of the Kenya Geological Survey, spent some time in the Lake Magadi area, and recorded certain geological facts which have proved most useful in the attempted correlation.

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(1) Guest N.J. & Stevens J.A. Lake Natron, its springs rivers brines and visible saline reserves. Mineral Resources Pamphlet No.58 of Dept. of Geol. Surv. Dodoma, Tanganyika Territory.
(2) Guest N.J. Gelai Magnesite. Mineral Resources Pamphlet No. 52 of Dept. of Geol. Surv. Dodoma, Tanganyika Territory.
(3) Report on work done on the Lake Magadi Problems up to July 1950. B.H.Temperley and A.O.Thompson. Geol. Surv. of Kenya, Nairobi.

Stratigraphy of Lake Natron

Mainly pre-Malambo faulting

As the figs. 5 &6 indicate both lakes at one time were very much larger than they are at the moment, and almost certainly were united.

In the L. Natron area, lake beds see fig.5, locality A, were mapped on the top of the western scarp overlooking L.Natron from just south of the Malambo delta, northwards to the western lagoon, and they extend even further northwards. Other lake deposits see fig. 5, locality B, were noted at the base of the scarp in the Humbu area, especially around the Peninj river, and at places in the rift wall scarp. The sandy yellow Shombole beds see fig. 5, locality E, were seen on a small saddle immediately to the east of Shombole, but elsewhere, on the lower ground have now been eroded away.

On the east side of L. Natron is a large virtually flat-bottomed depression called Kibangaini, which is almost surrounded by an area of small horsts and gräben of lava, known as "grid-faulting". Near, and actually in this depression, lake beds see fig.5, locality C indicate that at one time, it must have been part of L. Natron. To the south east of L. Natron there are deposits of magnesite see fig.5, locality D, lying near the present day shoreline, on the lower western flank of the volcano called Gelai. These Guest(1) considers to have been formed by chemical precipitation, in the much enlarged L. Natron, and are dealt with below.

The fullest stratigraphical sequence of these lacustrine deposits has been established to some degree, amongst the lake beds on top of the scarp in the Malambo river area.

At locality A see fig. 5 the following sections were observed:-

Diatomite, with much chalcedony and iron staining	25 - 30'
Green argillaceous beds, with small calcite crystals plus	8'

(1) Guest N.J. Gelai Magnesite. Mineral Resources Pamphlet No.52 of Dept. of Geological Survey, Dodoma, Tanganyika Territory.

While a little distance away in a small river course below the above:-

Yellow silt beds
Dark, compact, black-blue, spheroidally weathering lava - a nepheline-tephrite.

In a river section:-

Cherts.	
Diatomite - thin band.	
Upper Yellow Silt beds. Finely banded, argillaceous, texture very fine, but some bands containing tuffaceous green lapilli, considered to have been water deposited. Thickness estimated at	30'
Lava flow. Thickness estimated at	25'
Lower Yellow Silt beds. Yellow brown colour, banding generally absent, fine grained, probably aeoliandeposit. Thickness estimated at	20'
Lava - nepheline-basanitic affinities. Thickness estimated at .. .. plus	25'

In river section to north of Malambo and nearer rift scarp:-

Chert screes and capping.	
Dark, spherulitic, tephritic lava. Thickness estimated at .. .. plus	25'
Porcellaneous grey white band. Presumably the upper portion of the underlying yellow beds baked by the lava flow.	1'
Lower Yellow Silt beds. Thickness estimated at	25'
Purple-red bole. Thickness estimated at	40'

Another locality to the south of the R.Malambo:-

Purple grey volcanic ash.
Cherts.
Upper Yellow beds.

Combining the evidence of the different sections given above, a more complete idea of deposition can be constructed thus:-

		Estimated thickness
Volcanic ash.		
Chert horizon.		
Diatomite	- Sambu faulting during this period	25' - 30'
Green argillaceous beds		8' plus
	Malambo faulting Sambu lavas ?	
Upper Yellow Silt beds		30'
Lava		25'
Porcellaneous white band		1'
	Mosonik lavas ? commence	
Lower Yellow beds		25'
Purple red weathered lava, bole		40' plus
	Sambu lavas	
Lava		

It will be noted that at no one section is the complete sequence to be seen. There is ample evidence of unconformity, and perhaps non-sequences, no doubt due mainly to the faulting which was certainly very much more complicated than the above table indicates.

The position of the chert horizon is not very clear. Cherts, being very resistant to weathering, naturally tend to form a capping, where perhaps younger and softer beds, which at one time overlain them have since been eroded away. At L. Natron, cherts were definitely found forming screes on the diatomite deposits - and as thin layers overlying the diatomite. Some of these diatomite beds contain much chalcedony, often in the form of cherty bands, and it may well be thatmore detailed investigation will show some of the cherts originated from these bands. The purple weathered lava, or perhaps more correctly bole, seen in one locality only, in the area mentioned above, indicates that the basal lava flow, was here above lake level and was therefore subjected to erosion, and weathering. Elsewhere, the lava was being covered by the lower yellow beds, due to aeolian deposition at least to some extent. Both purple-red bole and yellow beds, are indicative of a warm climatic period.

Southwards from Malambo towards the old volcano of Mosonik, the alkaline lavas from this volcano, overlie some of the lower yellow beds, and are in their turn overlain by younger lake beds elsewhere. To the north, the older lava types from the volcano of Oldonyo Sambu, have a similar disturbing effect on the normal deposition of the lake beds sequence. It may well be that the bole referred to above is one of the earlier flows from Sambu.

Towards the north of the mouth of the Malambo river, the diatomaceous horizons become coarser and less pure. These beds are similar lithologically, to the horizontally bedded rather coarse, cherty, more areraceous, impure diatomaceous beds, seen still further north. They lie at the base of the scarp on the west shore of L. Natron where the Peninj river breaks through the rift wall and enters its delta.

A period of considerable faulting, culminating in the Sambu fault, took place possibly during, and certainly before the deposition of these coarser beds against the newly formed scarps. The older courser diatomaceous beds, on the top of the scarp, are possibly only facies variants of the purer diatomaceous beds in the south. Further detailed mapping will settle this point. Using all evidence available it is still rather difficult to place the period of faulting exactly. At locality A above the scarp the diatomite beds overlying the green argillaceous beds both appeared to represent one period of deposition. At locality A the diatomite beds rest with unconformity on the upper yellow beds; yet, actually to be seen on the rift wall fault scarp are downfaulted yellow beds, with overlying lavas, but nowhere, yellow beds, diatomite and lavas. The unconformity referred to above, which cuts out the argillaceous horizon, may well have been due to a period of faulting after the upper yellow beds were laid down. This means that these argillaceous beds, and the diatomaceous beds, were deposited in a larger lake in which diatomite was deposited above and below the scarp. According to Uhlig's map the lake must have then been standing at over 740 metres, and would cover the Kibangaini depression. This view is supported by additional evidence given below.

The coarser, arenaceous diatomaceous deposits to be seen on the west side of Lake Natron fig. 5, locality B, can also be correlated with similar lake beds mapped at the base of the eastern scarp of the Kibangaini depression fig.5, locality C, whilst in the same locality more argillaceous lake beds noted on a scarp face but not at the top of the scarp, may be correlated with the mud bands to the west of Malambo. The Kibangaini lake beds were also deposited after a period of faulting. Some of these lake beds contain silica-rich layers, calcareous, diatomaceous and argillaceous material, and elsewhere whitish-grey diatomite.

The period of Kibangaini faulting is considered to be contemporaneous with the normal Malabmo rift faulting, but the "grid-faulting" of Kibangaini, is part of a much more complex fault pattern, considered further later.

Additional evidence in support of these geological facts, as seen in the field can be obtained from a study of

Carl Uhlig's[1] original topographical map of the Lake Natron district. This remained the only topographical map until Guest and Stevens[2] compiled a map from aerial photographs, see fig. 4 .

A spot height on the floor of the present-day Kibangaini depression is shown as 633 metres, see also fig. 5 , that is, 23 metres above Uhlig's height for L. Natron. There is another spot height on the eastern scarp of Kibangaini indicating 718 metres, and one on the top of the horst for 838 metres. Lake beds were noted near the top of a gorge where a river from the east, enters the south-east end of Kibangaini. At this place, the gorge was cut through an estimated thickness of at least 80 metres of riebeckite-trachyte, exhibiting very fine spheroidal weathering in places, and overlying a vesicular basaltic type rock probably from Gelai. At this point the top of the gorge stands some 714 metres above the floor of the Kibangaini depression, and below the 718 and 838 spot heights. The lithologically similar diatomaceous beds in the Malambo area were found, according to Uhlig's spot heights, somewhere above 651 metres and below 741 metres approximately, although certainly nearer the higher level, due to the thickness of the beds below the diatomaceous deposits.

It would seem reasonable to correlate these two diatomaceous deposits tentatively; one on the west side of the lake at present situated at a height somewhere below but near to 741 metres, with the other lithologically similar deposit, on the east side of the lake, noted at about 714 metres but which may well have been originally deposited higher up the scarp face or on the summit of the horst.

Moreover, the lake beds in the Kibangaini depression were mapped mostly at the base of the eastern scarp, and towards the northern end of the depression; that is slightly above Uhlig's figure of 633 metres. On the Peninj lake beds, at the other

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(1) Uhlig C. Die Ostafrikanische Bruchstufe. Mitt. aus. den. Deutschen Schutzgebieten. Berlin 1909.
(2) Guest N.J. & Stevens J.A. Lake Natron etc. Mineral Resources Pamphlet No.53. Geol. Surv. of Tanganyika.

side of the lake, stands one of Uhlig's triangulation points indicating a height of 648 metres and the lake beds are certainly 10 metres thick in this locality. In other words, the Peninj and lower Kibangaini lake beds, which are also lithologically similar, appear to have been formed at the same lake level, and may therefore be correlated.

It should be stressed however, that this correlation should be treated with caution as northwards into Kenya, diatomite deposits occur to a great thickness, and appear to be often homogeneous. In the L. Natron region the hetrogeneous nature of the deposits make correlation more probable.

The L.Natron-Sambu faulting

Before considering the other lake beds deposited post-faulting, it may be well to collect all available evidence in connection with the main faulting in this region.

Trending northwards from the very low fault scarp, about 20-30 feet high, at the mouth of the river Malambo, the scarp increases in height to about 4,500 feet where the old volcano of Oldonyo Sambu has been dissected by a younger great fault, called here the Sambu fault. The small hills at the base of the highest remaining part of this volcano, named the Losideti hills, may well be part of the downfaulted summit of this old volcano, as Uhlig[1] had previously suggested. Examination and comparison of rocks from both the Losideti hills, and the summit of Oldonyo Sambu should help to prove this point, but has yet to be done. If the rocks are comparable, then a downthrow, of 4,500 feet to the west apparently as a normal fault, has occurred; if the rocks are not similar then the throw is more than 4,500'. The Sambu scarp, on morphological evidence alone is younger than the Malambo faulting. The scarp has not been breached at all by river erosion, and streams still exhibit a radial drainage pattern from the remaining half of the summit of Sambu.

A section on the rift wall at the south end of the west lagoon, which is considered to be part of the Malambo scarp, shows yellow lake beds with their accompanying lava flows,

(1) Uhlig C. Die sogenannte Grosse Ost Afrik. Graven. Geogr. Z. Vol. 13. 1907.

lying at the present base of the scarp, and overlain by a considerable thickness of at least five other lava flows. Each of these five flows except the upper oneforming the edge of the present scarp, are weathered on their upper surfaces to between 1 to 6 feet of bole. Sambu was therefore very active, volcanologically, before the Malambo scarp was formed. The Malambo scarp is cut off by the Sambu scarp at the north end of the Sambu delta and hence is the older.

A continuation southwards of the Sambu scarp, shows that it would pass under the volcanoes of Oldonyo L'Engai and Kerimasi, and continue along the steep scarp north and south of Engaruka. Both these volcanoes now obliterate any signs of the scarp in this area, as they are younger than the Sambu faulting. Oldonyo L'Engai is still active, and Kerimasi spreads over the Engaruka rift wall. It is this rift wall, some 3,000' at Engaruka, which exhibits a similar youthful aspect, although, unlike the Sambu scarp, it is breached in several places. To the west of the scarp in the Engaruka region, however, lies the Winter Hochland, an area of giant volcanoes and craters, some towering upwards to nearly 12,000 feet. Naturally, therefore, there would be a much greater precipitation, as compared with the low arid area west of Sambu. At least two rivers, the R.Engaruka being one of these, carry water down from these highlands, through the breached rift wall to the dry plains on the rift valley floor.

The Sambu fault was estimated to have a downthrow of at least 4,500' yet it appears to have no equivalent on the eastern side of the lake. Here the last episode offaulting may have been earlier, when the "grid-faulting" came into effect. The Sambu fault is therefore a trap-door fault, with the hingeline possibly somewhere under the present Lake Natron or on the eastern shore of the lake. If the above reasoning is correct, there must be a similar displacement in the post-Malambo fault lake beds through which the volcano emerged. Before the subsequent Sambu faulting dissected the mountain, Sambu must in some respects have resembled Kerimasi in its present form. It would be partially younger than the Malambo scarp over which it flowed in a westerly direction, although its earlier lava flows actually helped to compose the scarp. Kerimasi however is totally younger than the Engaruka scarp which its agglomerates now conceal.

Uhlig[1] refers to this fault as the Ostafrikanische Bruchstufe, but the L. Natron Sambu fault is considered a better name, as it immediately gives the locality of the fault. The "Lake Natron" part in the nomenclature of this fault is generally ommitted in this text, but is really necessary initially as there are numerous other Oldonyo Sambu mountains in Masailand; the words mean "the mountain of colours".

Uhlig[1] and later Bailey Willis[2] considered this Sambu fault to be younger than all other fault systems in this area, a conclusion arrived at by Guest in the field before the above works had been consulted. Previous workers relied mainly on morphological observations and did not use much additional geological evidence which is now given further consideration. It is useful at this point to refer to fig. 5 , showing the geology of the Lake Natron area.

It has been previously shown that the older lavas from many different localities have similar characteristics, likewise, in a general sense, do the younger more alkaline extrusives. Some correlation of rock types therefore, on either side of the lake is immediately possible, but a more detailed survey shows this is unlikely stratigraphically, and that most evidence points to the faulting postulated above.

For instance, to the east of the Kibangaini depression, and between the lake and this depression, there lies a plateau area consisting of distinctive riebeckite-trachyte, which was seen outcropping on the eastern shore of the lake. On the north-western side of the lake, at the base of the rift wall,

(1) Uhlig C. Die Sogenannte Grosse ost Afrik. Graben. Geogr. Z. Vol. 13. 1907.
(2) Willis Bailey. 1936 East African Plateaus etc. No.470. Carnegie Institution of Washington.

a careful search was made for this rock, but only Oldonyo Sambu rock types were noted.

Southwards, some of these Sambu lavas have been likened to similar types from Gelai, but generally speaking, any correlation petrographically across the lake is not practical. Most of Gelai consists of nepheline-melabasalts at the base of the volcano overlain by phonolitic-trachytes. Sambu is particularly rich in Kawenzi-type rocks, and has been suggested as being contemporaneous with Ketumbaine, which has been shown to be older than Gelai. However, anorthoclase phenocrysts were noted in one specimen from Sambu (JG991) and anorthoclase occurs in the SW corner of Gelai (JG923), but the rocks are not really identical.

Where the older lavas of the rift wall emerge in the south from the outpourings of Mosonik a nepheline-melabasalt lava (JG911), was found overlying a more andesitic rock (JG910) with possible nepheline. Some ten miles to the east similar rocks were found on Gelai, in fact the nepheline-melabasalt is particularly common on Gelai. Here therefore, is a place where correlation is possible, although it is considered very much more likely that the rift wall lavas originated from the volcanoes of the Winter Hoo-bland, to the west.

After the main faulting, lithological correlation by the lacustrine deposits has been shown to be possible.

At this point it should be mentioned that on the rift wall to the north end of the Sambu, that is where the Sambu fault cuts off the Malambo fault, considerable disturbances are shown in the downfaulted lake beds, and at one place aeolian and lacustrine deposits now appear to be infilling an old river channel, which must have existed before the Sambu fault originated.

<u>The lake beds later than the Sambu faulting</u>

After the period of Sambu faulting the geological succession has been worked out as follows, although this sequence certainly only represents the very much younger beds.

what kind of lake beds accumulated on the downfaulted sides of Sambu will only be proved by boreholes, although geophysical evidence may well outline the extent of the submerged Sambu, and possibly suggest the type of lake beds deposited at depth.

Period of desiccation. Evaporite series. Volcanic ash deposition, and formation of the Shombole yellow beds.
Further lacustrine deposits as yet unknown.
Deltaic deposits.
Magnesite deposits. Shombole extrusives
Diatomite deposition, generally rather impure deposits.
------------------Sambu faulting--------------------

The above table can only be considered in allrespects, as very approximate.

It is interesting to note that Shombole must have originated after the Sambu faulting, because it shows no sign of tilting, which one would otherwise expect to see. Shombole may be correlated tentatively with Oldonyo L'Engai to the south, which is still active because both consist of the same soda-rich alkaline suite of rocks. It would appear that the downthrow of the Sambu fault may have provided the necessary increased pressure on the parent magma leading to the eruption of these sodic-alkaline lavas.

The Magnesite deposits

It has previously been postulated by Guest[1] that the most probable method of origin for the Gelai magnesite, situated on the flanks of an old volcano, see fig.5, locality D, was by precipitation from magmatic fluids and gases into the older and larger lake. These magmatic fluids and gases may well have been connected with the Gelai volcano, and they would have made available a solution of magnesium sulphate. This solution would be brought into contact with the waters of the lake up lines of weakness connected with the "grid-faulting" to the north. The magnesium sulphate would then react with the ubiquitous sodium carbonate in the lake, and magnesite would be deposited. Magnesite has only been noted in the one locality in this area, and may equally as well have been formed prior to

(1) Guest N.J. Gelai Magnesite. Mineral Resources Pamphlet No.52. Dept. of Geol. Surv. Dodoma, Tanganyika Territory.

the Sambu faulting.

The Deltaic deposits

With a fall in base level after the Sambu faulting, resulting in the downthrow of the inner part of the then more extensive L.Natron, the main rivers feeding the lake would be rejuvernated and vigorous downcutting would commence. The more resistant lava flows would be an immediate obstacle, compared with the softer lake bed series, but especially as the lake waters receded and the lake as we know it today took shape; there would come a time when the rivers would breach the lava flows, as witnessed by numerous quite spectacular gorges cutting rhough the rift wall and thence deposit their loads in the younger lake. At this particular period the rivers Peninj and Malambo or Haoik, both rising in the highlands of the basement complex to the west, built up their large deltas known as the Humbu and Malambo deltas respectively. Deltaic deposits consist mainly of well rounded, often very clear, glassy quartz grains, in striking contrast with the volcanic rocks to be seen elsewhere in this neighbourhood. Only nearer the rift scarp do the volcanic debris form the more recent deltaic beds.

To the east of L. Natron the faulting is not so severe, and the rivers from the basement area highlands, further to the east, still deposit their loads only as far west as the south-east corner of the Kibangaini depression. The Engare Naibor is the largest river on this side of the lake, yet does not enter the present L. Natron.

The Volcanic Dust

This was noted with cherts overlying yellow beds to the south of the river Malambo on top of the scarp; the very fine ash must have been deposited after one of the more recent eruptions of Oldonyo L'Engai to the south since nearer this volcano, similar purple ash was noted on the banks of the main river between Kerimasi and L'Engai, and on Oldonyo L'Engai itself, near the overhanging rock on the western flank at about 9,000 feet.

The Evaporite Series

Some details concerning these deposits were given by Guest and Stevens[1] in 1951, but little attention was then devoted to their geological setting, as the 1951 report was written essentially from an economic point of view, and was, in any case, only interim in nature.

After the passing of the last Pluvial period in the late Pleistocene the waters of L. Natron, along with the other E. African lakes, retreated considerably. If the recent alarming retreat of the glaciers on Kibo is solely indicative of a general rise in solar temperature, then these lakes should be continuing to retreat today. The eruption of Shombole, at the north end of L. Natron, would also assist in the division of L. Magadi from L. Natron.

The small volcano of Shombole rises to just under 5,000 feet above sea level, 3,000 feet above lake level, and consists of nephelinitic-phonolite ashes, lavas and tuffs, and belongs to the alkaline volcanic group. As the period of desiccation proceeded, the Shombole yellow beds were formed almost certainly by aeolian action, and now only remain on the higher part of the saddle between Shombole and Elashu further to the east.

From less than a dozen boreholes, none greater than 20 feet in depth, the upper evaporite succession has been temporarily worked out, and is perhaps best explained with the aid of a section across the lake see fig. 7 . This section indicates the greatest thickness of surface salts - that is up to 20' in depth - is a little nearer the Sambu fault, than the eastern side of the lake. Also, the soda salt crust was slightly thicker at borehole 6, at the base of the Sambu fault, than on the eastern shore of the lake, and thirdly,

(1) Guest N.J. & Stevens J.A. Lake Natron, its springs, rivers, brines, and visible saline reserves. Mineral Resources Pamphlet No.58 of The Dept. of Geological Survey, Dodoma Tanganyika Territory.

the pink concentrated brine was standing deepest near the base of the Sambu volcano; and incidentally, the analyses of spring waters here showed a marked increase to 30 - 40% NaCl content.

All these factors point to evidence for a slightly lower surface of the lake opposite Sambu. The lake has possibly not yet attained a level upper surface, although this is nearly the case. The section fig. , indicates that the thickest deposits of salts occur almost in the centre of the lake. This apparent slight tilting may be due to recent movements along the Sambu fault.

Stevens' work on the soda salt crusts and the mud deposits of L.Natron will no doubt add to our knowledge of crystallization. At the moment it can be stated NaCl comes down last, and the remainder of the crust consists largely of Na_2CO_3 in some form; more commonly as trona, although thermonatrite was collected from the surface of the lake. In places, see fig. 4 sub-circular areas, possibly due to wind sorting, of a particularly flaky-crust were noted, which, on the strength of one analysis alone appears to be rich in sulphate.

Beneath the crust are more layers of trona situated in mud, generally very black in colour, to a depth of 10'. It is perhaps of interest to record cavities beneath the surface crust in some areas, and the presence of gas bubbles in most auger holes.

The surface deposits of soda salt crusts lie in polygonal shaped sheets about 10 yards in radius, and their edges are buckled up by overthrusting against the edge of the neighbouring polygons. Up these small areas of displacement mud and brine reach the surface, and this may be due to convection currents. Similar features can be seen in vertical section in the salt mine at Winsford, Cheshire.

Origin of the salts

This was considered in a preliminary manner by Guest and Stevens[1], and few additional details have subsequently come to light which would lead to any further conclusions. Stevens through the evidence of his analyses showed that there appeared to be "a high-level body of ground water to the south west of the lake" and "elsewhere in the lake basin however, the analyses of the spring solutes, their high concentration in many cases, and the enormous daily input compared with the visible reserves of saline material in the lake, makes it very probable that they consist largely of re-cycled material picked up by meteroic water at its contact with deep, dense and strongly saline ground water".

Guest considered that some of the spring water may be juvenile in origin, as mentioned in connection with the possible formation of the magnesite at Gelai. The same magmatic source may well be responsible for the steam and fumaroles noted in the northern crater of Oldonyo L'Engai in 1950 and 1951.

A lot of the salts are certainly leached out of the sodic alkaline lavas and ash during the normal course of weathering, and these would be carried by the rivers in solution and suspension, during the rainy season, to the lake. The dry river beds in the Oldonyo L'Engai neighbourhood, and the northern crater of Oldonyo L'Engai are encrusted with much white soda[A]. Richards[1] collected some of this white crust[A] and a brown powder[B] whilst investigating the 1940-41 eruption. Stevens showed the crust and powder to consist approximately of the following, amongst other constituents:-

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(1) Guest N.J. & Stevens J.A. Lake Natron, its springs, rivers, brines, and visible saline reserves. Mineral Resources Pamphlet No.58 of The Dept. of Geological Survey, Dodoma, Tanganyika Territory.

TABLE NO. 27

	A	B
SiO_2	34.60	0.16
Al_2O_3		
Fe_2O_3	20.70	11.99
FeO		
CaO	17.25	6.82
Na_2CO_3	6.6	40.00
NaF	0.15	-
$NaCl$	0.69	-
Na_2SO_4	0.76	6.4
MgO	-	0.38
K_2O	-	0.37

One of the rocks collected by Richard[1] from Oldonyo L'Engai shows 14% Na_2O, on analysis.

In this connection the geological sketch map fig. 2 indicates that a belt of sodic alkaline rocks stretches southwards from Shombolo, under L. Natron possibly, and that such rocks from Mosonik and L'Engai are exposed on the southern shore.

Thence, this belt continues further southwards to Kerimasi and at least as far as Embagai. It is concluded that the soda and salt deposits of L. Natron owe their origin in no small manner to the sodic alkaline volcanoes in this area.

Attempted correlation with Lake Magadi lake beds

Lake Magadi in Kenya, lies within 20 miles NNE of the northern shores of L. Natron, and is in fact, almost due north of the Kibangaini depression. Both Kibangaini and Magadi lie in the area of grid-faulting.

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(1) Richard J.J. Volcanological Observations in East Africa, 1. Oldonyo L'Engai, the 1940-41 Eruption. Jour. East Africa and Uganda Nat. Hist. Soc. Vol. XVI Nos. 2 and 3. pp. 89 - 108.

A comparison of the succession is as follows:-

Lake Natron	Lake Magadi[1]
Evaporite series	L. Magadi evaporites
Volcanic ash.	
Unknown lake deposits	
Partial aeolian erosion of Shombole yellow beds.	Aeolian erosion
Shombole yellow sandy beds.	
Desiccation	Desiccation
Shombole volcanics	
Deltaic deposits	
(Lake level higher than to-day)	(Lake level higher than today)
Magnesite deposits	
Faulting	High Magadi Series:- aeolian deposited; derived from Chert Series.
Impure diatomite with siliceous bands	Diatomite to north in great trap-door fault.
Major Sambu faulting	
Diatomite, often impure with silica.	
Sambu volcanics	
Grid faulting and development of Kibangaini depression	L. Magadi trough formed.
Malambo faulting	Major grid faulting.
Sambu volcanics	
	Erosion.
Diatomite with cherts	Silica veining in Chert Series.
	Local limestone on Chert Series.
	unconformity
Sambu volcanics	Chert Series:- (deposited in narrow troughs.)
Green argillaceous bed	Yellow green silts with silica interbedded.
	Local limestone.
Sambu volcanics	
Upper yellow series	Sandy non-siliceous beds with calcification
Sambu lava	
Porcellaneous white band Sambu volcanics	
Lower yellow series	? Sandy non-siliceous beds etc.
Dolo, locally formed Mosonik volcanics	
Sambu lava	
Sambu volcanics	unconformity
	? Faulting
Plateau lavas - Kibangaini trachytes	Plateau lavas
	unconformity
	Intrusive porphyry

(1) Temperley Dr. B.H. & A.O.Thompson 1950. Report on work done, on the L. Magadi problems up to July 1950. Geological Survey, of Kenya, Nairobi.

As far as can be ascertained, the above is the first attempt at a stratigraphical correlation between the two lakes. Owing to their proximity, it is natural to expect a similar geological history to be shown in the deposits of both lakes, although volcanic eruptions together with periods of faulting have complicated things considerably.

In the Natron area, the Sambu faulting is considered of major importance, but at Lake Magadi, which lies further to the east of the western rift scarp, the possibly earlier grid-faulting period is naturally considered of first importance. Temperley and Thompson[1] however, believe further faulting to have occurred after the main grid-faulting; they mention diatomite being laid down to the north in a great trap-door fault, which is tentatively correlated with the Sambu fault of a similar nature. Temperley and Thompson maintain that their Chert Series was laid down in narrow troughs, suggestive of an even earlier grid-faulting phase, which has so far not been noticed in the Lake Natron area.

Mention should be made of Thompson's[2] recent and so far exclusive discovery of a small deposit of sodium nitrate south of Lake Magadi, which seems to have been formed under rather unusual conditions.

None of the beds mentioned above have so far yielded fossils or implements, except the diatomite deposits referred to in the Kenya report; it is not possible therefore, to date any of the above events without comparison with other areas where faunal remains have been found. The Olorgesaile diatomite beds to the north of Magadi perhaps the nearest known fossiliferous deposits, are considered by Cole[3] to be Middle Pleistocene, and were faulted after formation, probably

(1) Temperley Dr.B.N. & A.O.Thompson 1950. Report on work done, on the L. Magadi problems up to July 1950. Geological Survey of Kenya, Nairobi.
(2) Thompson A.O. An occurrence of Nitrates in Kenya. Col. Geol. & Min. Res. Vol. 1. No.4. 1950. P.365.
(3) Cole S.M. An outline of the Geology of Kenya. Pitman.

in the Upper Pleistocene. By analogy, it is suggested that the Sambu fault also occurred at this time.

Utilising the spot heights on Uhlig's map, it has been possible to estimate the outline of the extended Lake Natron, as it would have been when the lake beds were deposited at about 750 metres. See fig. 5 and also fig. 6 . The latter sketch map indicates the approximate boundary of the present day 3,500 foot contour and emphasises how the lake probably continued to be an area of inland drainage up to a height of between 3,500 and 4,000 feet. The Kibanagini depression would have remained connected to Lake Natron as long as the water level did not fall below somewhere between 700 and 750 metres, about 2,310 to 2,475 feet.

Petrogenesis

In the preceding sections petrological accounts have been given of the various and sometimes unusual volcanic types which were found in the northern part of the Gregory Rift Valley in Tanganyika while an attempt has been made to outline the stratigraphy and tectonic pattern of the region as a whole. It has been noticed that the so-called older extrusives are closely related to the younger extrusives in place and time. Mosonik of younger extrusive lava type was apparently being formed almost if not contemporaneously for at least part of the time, with Oldonyo Sambu, of older extrusive lava type. On the other hand, Shombole, of the more sodic younger volcanoes probably ceased erupting before some of the volcanoes of the supposed older extrusive lava-type such as the later extrusions of Kibo on the Kilimanjaro massif. Besides this overlap in time, the later older extrusives are at times very similar petrographically to some of the younger extrusives, and indeed, it is difficult if not impossible, to know where to place a suitable dividing line. The provisional classification by relative age however, still holds when it is remembered that the oldest lavas in this area are andesitic, and the youngest lavas are rich in nepheline and aegirine-augite.

The youngest volcano of all, Oldonyo L'Engai, which is still active, showed indications of fumarolic activity in 1951, which was less noticeable compared with the fumaroles seen in the inner crater on Kibo in the same year.

Kerimasi, one of the younger volcanoes, is perhaps the most interesting and unusual of all the volcanoes in this region. It has been shown to consist essentially of calcareous agglomerate, and carbonatite fragments, but is not the youngest volcano. Its origin therefore, appears to have been due to some local development under rather special conditions.

The sketch map fig. 2 , indicates that the older lavas cover a more extensive surface area, and were extruded from many more larger volcanoes.

The older extrusives

Most of the older extrusives have the appearance of basaltic rocks macroscopically and in the literature of this region, basalt and trachydolerite are terms extensively used.

An examination of the thin sections of the plagioclase feldspars in the specimens collected, has shown the commonest plagioclase to be andesine and not labradorite, and the rocks therefore are more closely allied to andesites than to basalts.

In 1934 Oates[1] describing rocks from Mount Meru and Kilimanjaro, noted types varying from "trachytic to basaltic" from the Mawenzi peak of Kilimanjaro, and other similar rocks he referred to tentatively as "trachybasalts". In the same report, Teale reported a series of rocks from Mawenzi, which he maintains extend from trachyandesite to limburgite.

In 1916 Holmes[2] mentions various types of andesites from the East and Central African area, and quotes two analyses from Mount Meru, which are given in table No.28. He also mentions that Bornhardt found basalts, andesites and trachytes north of the River Songwe in southern Tanganyika and goes on to state (p. 262) "the alkali series, often accompanied by normal basalts, is later".

More recently King[3] reported an andesitic lava flow on the northern face of Napak, and gives an analysis which is likewise included in table No. 28 below. According to King, this rock is high in total iron and thus differs from the andesites of Holmes and "the high Na_2O / K_2O ratio (4.40 : 1.80) as well as the relatively high lime are probably to be regarded as indications of close affinity with the nephelinites. It is instructive to note that the "andesine-andesites" of Hawaii are also rich in Fe and lime.

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(1) Oates F. Annual Report 1934, Dept. of Geology, Tanganyika Territory. p.27.
(2) Holmes A. The Tertiary volcanic rocks of Mozambique 1916. Q.J.G.S. Vol. lxxii pp. 223 - 279.
(3) King B.C. The Napak area of Southern Karamoja, Uganda. Geol. Survey of Uganda. Memoir V.

TABLE NO.28

E. African Andesites Chemical Analyses

	No.1	No.2	No.3	No.4
SiO_2	51.32	56.65	53.54	48.76
Al_2O_3	16.62	22.11	15.78	15.82
Fe_2O_3	9.28	3.31	12.90	4.10
FeO			.96	7.53
MgO	5.36	3.42	.44	4.74
CaO	9.62	6.67	4.80	7.99
Na_2O	2.15	1.66	4.40	4.50
K_2O	2.96	4.10	1.80	1.58
H_2O +	2.60	2.20	2.32	-
H_2O -			.36	
TiO_2	n.d	n.d	1.03	3.29
P_2O_5	0.25	tr	1.65	.72
MnO	0.55	0.16	.14	.17
CO_2	-	-	.33	-
BaO	-	-	.02	-
	100.71	100.48	100.47	(99.20)

No.1 Olivine-Augite Andesite, Mount Meru, L. Pinkert, Földt. Közl. Vol. XXXVII (1907) p.292.

No.2 Amphibolite-Biotite-Andesite, Mount Meru. Id. Ibid. p.296.

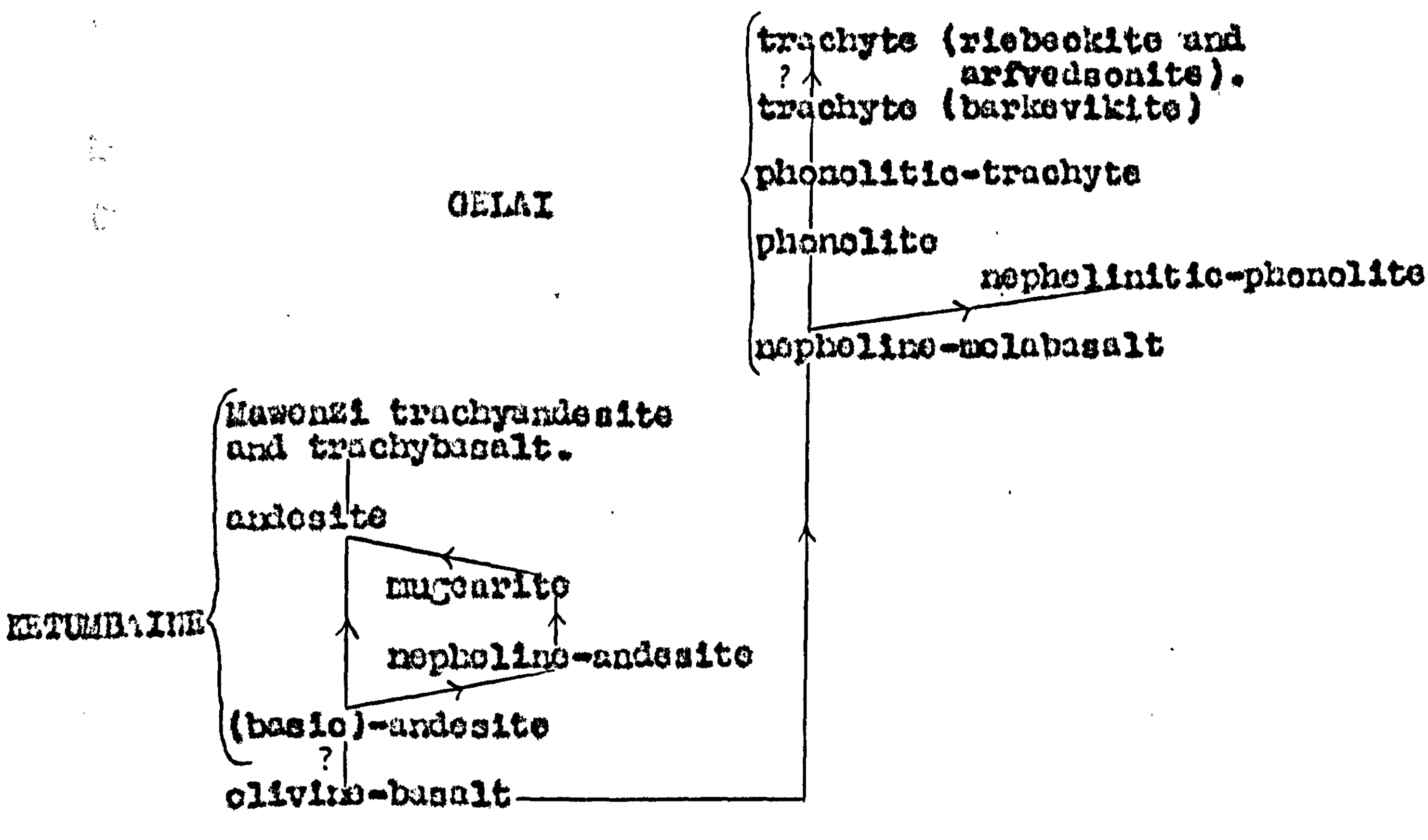
No.3 Andesite, Napak, Analyst. B.C.King, King Napak Area of S.Karamoja, Uganda, Memoir V. Geol. Surv. Uganda 1949.

No.4 Andesine Andesite; Average of 21 Analyses, Hawaii.

Andesites, therefore, are not uncommon in East Africa, and it is expected they may well be more extensive at the expense of the basalts when further microscopical determinations have been carried out on the plagioclase feldspars, with additional chemical analyses of the rocks. It has been shown above that many of the rocks in this region contain feldspars which, microscopically place the rocks on the border-line between andesites and basalts and in these cases the term basic andesite has been used.

It has been mentioned previously in the section on petrographic descriptions of the older volcanics of this area, that they exhibit a magmatic trend which can be summarised as follows:-

Magmatic trend - older extrusive rock types



From the above diagram, based on field evidence, the observed "parent magma" is an andesite with basic andesine feldspars. In other regions it has been suggested that rocks of this type have been derived from an olivine-basalt type of magma and so the latter may be considered to be the actual parent magma, although in this region, there is little field evidence available at the moment to support this supposition.

The problem of the origin of andesites has been recently examined by Tilley[1] who, states - "true andesites are unknown in the oceanic islands, for rocks so called from these localities are alkali types like mugearites or trachybasalts" - and in so doing disagrees with MacDonald[2] who, in his work on Hawaii describes rocks as -

	phenocrysts	ground mass
"andesine-andesites"	Ab 20-70	50-70
"oligoclase-andesites"	Ab 45-80	70-85

The "andesine-andesites" are gradational to basalts. Some of the "oligoclase-andesites" have long feldspar phenocrysts, at times exhibit trachytic texture, and contain a little aegirine-augite and possible riebeckite. Both types, therefore, are very similar to rocks already described from the volcanoes of Gelai and Ketumbaine and parts of the rift wall.

Returning to the recent suggestions of Tilley[1], who having synthesised the possible modes of origin of andesite, finally states there appears to be some connection between "basaltic magma and andesitic genesis"; qualifying this remark later by "the manner of the linkage is however, not so clear, and in particular whether some process supplementary to fractional crystallisation of basalt is not involved in the production of andesite".

Without any chemical analyses of the andesitic types collected from this region, it is not possible to make any really constructive suggestions which may throw a light on the origin of the andesites in this area. Their close affinity to basalts in some cases has been stressed.

It has been mentioned that a large block of granitic-gneiss was found in one of the older Ketumbaine lava flows. Although an isolated occurrence, this is nevertheless significant in drawing attention to the fact that, as these

(1) Tilley C.E. Some aspects of magmatic evolution. Pres. Add. Geol. Soc. London 1950.
(2) MacDonald G.A. Hawaiian petrographic province. Amer. Geol. Soc. Vol. 60 p.1541-1595

older volcanoes began to form, after the first of the more recent periods of rift faulting, the magma must have digested a fair amount of basement complex rocks, through which it had to force a passage before it could reach the surface. The intimate relationship of volcano and basement can still be seen in the area where Uhlig suggested thrusting may have occurred, on the north flank of Oldonyo Sambu.

It is probable therefore, that the postulated olivine-basalt parent magma, should by differentiation and some assimilation of the country rock, produce a basic-andesitic magma of the type seen around the base of Ketumbaine. Some of the younger rocks on Ketumbaine are the Mawenzi-type of trachyandesites where the feldspar can be labradorite, and the rocks therefore are strictly trachybasalts. This could be accounted for perhaps by assuming that at this period, the magma did not contain so much digested basement material.

Mugearites were also noted on Ketumbaine beneath the trachyandesites, and both of these "andesitic" types, according to Tilley[1] are found in oceanic islands and have been shown above to be very similar to rocks described by MacDonald[2] from Hawaii.

The complimentary heavy magmatic fraction was later extruded as the first extensive flow of lava from the volcano of Gelai. It is a basic rock, generally lacking in feldspar, but rich in olivine and the rock has been called a nepheline-melabasalt. This rock resembles in some respects the nepheline and labradorite bearing atlantites of Lehmann[3] from the Rungwe volcanic area in southern Tanganyika, where pyroxene is more common than olivine. An analysis of atlantite is given below in table No.29 together with analyses of nepheline-basanite, olivine-basalt, and andesine-andesite from the Hawaiian petrographic province.

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(1) Tilley C.E. Some aspects of magmatic evolution. Pres. Add. Geol. Soc. London 1950.
(2) MacDonald G.A. Hawaiian petrographic province. Amer. Geol. Soc. Vol. 60.pp.1541 - 1595
(3) Lehmann. Zeitschr. f. Vulkanologie. Erg. IV 1924. p.119.

TABLE NO. 20

Chemical Analyses - Atlantite Nepheline-Basanite Olivine-Basalt And Andesine-Andesite

	No.1		Mode	No.2	No.3	No.4
SiO_2	42.98			45.00	48.35	48.76
Al_2O_3	14.95			13.00	13.18	16.82
Fe_2O_3	6.24			4.04	2.[illegible]5	4.10
FeO	7.53	Labradorite	31	8.32	9.08	7.53
MgO	7.63	Nepheline	11	9.03	9.72	4.74
CaO	11.77	Apatite	2	10.16	10.34	7.90
Na_2O	3.63	Pyroxene	42	4.75	2.42	4.50
K_2O	1.43	Olivine	8	1.18	.58	1.68
H_2O +	.57	Ore	6	-	-	-
H_2O -	.28			-	-	-
TiO_2	2.10			3.10	2.77	3.29
P_2O_5	1.00			.40	.34	.72
MnO	n.d			.11	.14	.17
CO_2	-			-	-	-
	100.21					

No.1 Atlantite, Kungwe, Nyassa, E. Africa. Type. Analyst, Lehmann. Zeitschr. f. Vulkanologie, Erg. IV. 1924 119.

No.2 Average of 5 analyses of Nepheline-basanite, Hawaii.

No.3 Average of 53 analyses of Olivine-Basalt, including one Olivine-Gabbro, Hawaii.

No.4 Andesine-Andesite; average of 21 analyses, Hawaii.

Similar rocks have been noted previously from the Oldonyo L'Engai region, and other parts of Tanganyika, and have generally been called nepheline-basanites. In 1934 Teale and Oates[1] found nepheline was probably present in the groundmass in some rocks from the Shira peak on Kilimanjaro, and stated that the Shira nepheline-basanites showed phonolitic affinities whilst others "grade into types in which feldspathoid is less conspicuous, such as atlantite, trachybasalt etc."

A point in favour of the settling of the olivine crystals, is that in thin sections olivines have been found enclosed in nepheline crystals, yet the crystallization period of the two must have overlapped to some extent since in the same slide the olivines are themselves seen enclosing nepheline, e.g. JG800.

At the same time the presence of the undersaturated felspathoid in place of the feldspar, indicates desilication of the parent magma.

Returning to the Hawaiian petrographic province, MacDonald[2] has demonstrated that desilication alone would not produce these undersaturated lavas, which could only be explained - "if the rocks are end magmas resulting from long crystallization of a cafemic submagma, enriched in sunken crystals and possibly in sedimentary lime. Even without addition of limestone, such a magma would be rich in volatiles".

It is believed that a similar state of affairs existed in the Oldonyo L'Engai region. After the cone of Ketumbeine had been built by lava flows to a height of about 9,600 feet above sea level, there may well have been a considerable lapse of time, before the nepheline-melabasalts were extruded, probably as the initial lava formation of the Gelai volcano.

The important point at this stage is to note, as MacDonald[2] has suggested, that in order to account for

(1) Teale & Oates 1934 Ann. Rpt. Dept. of Geology, Tanganyika Territory.
(2) MacDonald G.A. Hawaiian petrographic province. Amer. Geol. Soc. Vol. 60 pp.1541-1595

nepheline-melabasalt, the assimilation of a small amount of limestone may be suspected, and would indeed be helpful theoretically, in assisting to explain the high CaO content of these rocks; although, it is quite appreciated that it is not necessary to assimilate limestone to arrive at the same conclusion. Similar rocks in other petrographic provinces may well have no connection with limestone at all.

Overlying the nepheline-melabasalts of Gelai, are the more siliceous phonolites, which in turn grade upwards into phonolitic-trachytes, and trachytic rocks containing barkevikite. These trachytes are similar to the Kibangaini trachytes containing riebeckite and arfvedsonite in preference to the barkevikite amphibole. There is no evidence at the moment to indicate that the Kibangaini trachytes are anything but plateau lavas of small scale fissure eruptions. Petrogenetically, they would fit into the regional magmatic trend, at this stage without assuming any major modifications of the light fraction of the magma.

Similar extrusions of trachytes in the whole of the Gregory Rift Valley, are indicative of a very much larger regional magma of this composition, which may well have undergone a magmatic history comparable to that outlined above.

A small volcanic cone, and marked feature on the western flank of Ketumbaine is called Loigurdolgonja . Here phonolites and nephelinitic-phonolites were collected, while similar rocks were noted forming small hillocks at the base of the rift wall in the Engaruka and Oldonyo L'Engai areas, and are thought to be products of fissure eruption. All these rocks contain more nepheline than the nepheline-melabasalts, and therefore it is argued, may well represent extrusives of a magma showing increased undersaturation.

We have therefore, besides a series of more siliceous - light fraction - differentiation products, as seen on the higher flanks of Ketumbaine and Gelai, a general trend towards greater undersaturation on the part of the parent magma, a point which is taken up in detail later.

Inclusions of dunite are a feature of some of the early lava flows on Oahu, and of the lavas of Hawaii. Elsewhere in the Hawaiian archipelago, MacDonald[1] reports alkaline lavas where "peridotitic and gabbroic cognate inclusions are common". But in this respect, and at this point, the similarity between these two petrographic provinces ends.

Tilley[2] has noted that the "andesitic" stage of the Hawaiian volcanic evolution, is comparable to the Mull alkali-magma series, and he goes on to say with reference to the Hawaiian region, that "this alkaline magma, like its counterpart on the continental areas, is a differentiated series partly diverging to phonolite but ranging through trachyte to pantellerite, the typical acid alkali end-product".

At the beginning of the century several of the early German workers on volcanological problems in East Africa, appreciated the similarity between some of the East African lavas, and those known from Pantelleria. A quarter of a century later W.Campbell Smith[3] demonstrated to an even greater extent, the very striking close relationship of certain rocks from these two areas.

<u>The nephelinitic-phonolites common to both the older and younger extrusive periods</u>

The older extrusive phonolites, and more especially the nephelinitic-phonolites, are comparable to many rocks of the younger more alkaline extrusives which are particularly common on Mosonik, the oldest volcano of the younger extrusive group, and to many of the lava flows from the active volcano, Oldonyo L'Engai.

To some extent the six analyses in table No. 30 help to illustrate this point, although no chemical analysis has been made of an older extrusive nephelinitic-phonolite in this district. The nearest example is the phonolitic-trachyte from

(1) MacDonald G.A. Hawaiian petrographic province. Amer. Geol. Soc. Vol. 60 pp. 1541-1595.
(2) Tilley C.E. Magmatic evolution. Pres. Add. Geol. Soc. London 1950.
(3) Cambell Smith W. A classification of some rhyolites etc. Q.J.G.S. Vol. 87. 1931 pp.212-258.

TABLE NO. 30

Chemical analyses of some Nephelinitic-phonolites and Phonolites from the N.Province, Tanganyika Territory

	JG965	JG860	No.1	JG694	No.2	JG923
SiO_2	46.40	49.57	53.12	53.35	54.20	54.34
Al_2O_3	19.63	18.53	21.62	19.98	19.38	20.35
Fe_2O_3	3.03	4.28	3.46	3.20	3.63	1.02
FeO	5.04	2.07	1.94	2.37	2.14	3.06
MgO	1.15	.08	1.10	.70	1.36	.78
CaO	7.50	5.44	2.00	3.12	2.16	2.23
Na_2O	9.30	9.36	8.10	9.48	8.01	7.59
K_2O	3.07	3.88	5.11	4.46	6.26	5.88
H_2O +	n.d	1.85	2.56	1.06	1.04	1.56
H_2O -	.40	1.68		.62		.54
TiO_2	1.06	.64	0.68	.97	0.70	.31
P_2O_5	n.d	.23	.46	.08	.58	tr
MnO	.01	.18	tr	.42	tr	.46
CO_2	n.d	2.03	-	-	-	tr
ZrO_2	-	-	0.06	-	0.47	-
BaO	.04	-	-	-	-	-
SO_3	.04	-	0.28	-	.31	-
F	.13	-	-	-	-	-
Cl_2	.16	-	-	-	-	-
	(96.34)	100.01	99.95	99.67	99.53	99.72

JG 965 Partial analysis by Dept. of Glass Technology, Sheffield University, Nepheline-phonolite, Mosonik.

JG 860 Nephelinitic-phonolite, Lava flow about 9,000 feet on west flank of Oldonyo L'Engai. W.H.Herdsman Analyst.

No.1 Nepheline-rhombporphyry, N.E.Kibo, Kyme Analyst.

JG 694 Nephelinitic-phonolite, Oldonyo L'Engai, W.H.Herdsman Analyst.

No. 2 Leucite-Rhombporphyry, E.Kibo. Klüss Analyst.

JG 923 Phonolite base of SSW flank of Gelai W.H.Herdsman Analyst.

Gelai, which obviously contains more SiO_2. The two analyses from Kibo are instructive, one a nepheline rhomb-porphyry, the other a leucite rhomb-porphyry, and both intermediate in composition between the Mosonik and Gelai analyses in the same table and therefore possibly similar to the nephelinitic-phonolites of the older extrusive type referred to above (p.150).

In thin section the Kilimanjaro rhomb-porphyries resemble the more phonolitic of these nephelinitic-phonolites, and from field evidence must represent one of the younger of the older extrusive lavas. That similar phonolitic rocks occur over a wide area in East Africa, has previously been demonstrated by Prof. J.W.Gregory[1], Campbell Smith[2] and others.

A comparison between the analyses of the younger extrusives, that is J6965 from Mosonik, and J6868 and J6894 from Oldonyo L'Engai, with the phonolitic rock J6923 from Gelai, indicate a marked decrease in SiO_2 and a small decrease in Al_2O_3 a noticeable increase in CaO, and an increase in Na_2O and TiO_2 with a possible increase in P_2O_5. These rocks are the most siliceous of the younger volcanics, yet even at this stage indicate with certain modifications, the same characteristics to be seen noticeably in the more desilicated rocks mentioned later.

It has been suggested that the trend of increasing undersaturation up to this point may best be accounted for by the process of magmatic differentiation by crystal settling, accompanied in all probability, by the assimilation of some limestone.

It is further suggested, that at this stage, which follows the last period of rift faulting of considerable magnitude - probably of late Pleistocene age - the existing nephelinitic

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(1) Gregory J.W. 1921. The Rift Valleys and Geology of East Africa. London 8 vo.
(2) Smith Campbell W. 1931. A classification of some rhyolites etc. Q.J.G.S. Vol. 87. pp.212-258.

phonolitic magma now assimilated limestone to an even greater extent than that previously postulated, producing as a result, a suite of rocks which tend to become progressively richer in their CaO content. Evidence for the assimilation of limestone is not only shown by the lighter magmatic fraction, but also by the fact that melilite-basalt is probably produced from the basic parental magma. The latter point is dealt with later.

The fenites and tveitasites of Oldonyo L'Engai

Amongst certain rocks found only on Oldonyo L'Engai are examples of fenties and tveitasites which have already been described petrographically. Johannsen's[1] remarks on the modes of origin of these rocks have been noted see p. 89. More recently von Eckermann[2] has introduced the term "fenitisation" and has studied this process in great detail in the rocks from Alnö. There seems to be little reason for doubting that these rocks, typical of several alkaline provinces have been formed by this process, and the inevitable close association of parent magma and the basement rocks is therefore confirmed.

Erdmannsdorffer[3] apparently quoting from the early records of the German explorers, reported many rocks of basement complex origin, occurring as ejectamenta around the flanks of Oldonyo L'Engai; details of these rocks have been given above see p. 83 when dealing with the previous work on this region. The rather more common ejected blocks of basement must have been visible before the 1917 eruption, when lava flows were noted from the volcano. Since 1917 there have been at least three other eruptions all of which appear to have covered much of these basement ejectamenta, which were certainly uncommon during the 1950 and 1951 investigations

(1) Johannsen A. 1938. A descriptive petrography Vd. I-IV.
(2) Eckermann H von. 1948. The alkaline district of Alnö island. Sveriges Geologiska Undersökning. Ser. ca. No.36
(3) Erdmannsdorffer O.H. 1935. Uber Wollastoniturtit und die Enstehungsweisen von Alkaligesteinen. Sitzungsberichte der Heidelberger Akademie der Wissenschaften. Maths. Kl.

of the writer. Microscopical study has revealed the strong resemblance of some rock fragments, especially from Kerimasi, to typical basement complex types.

There is the additional evidence of the intimate relationship of lava and basement, as seen today on the northern flank of Oldonyo Sambu, where both intrusive and extrusive "lava" was noted.

The formation of the alkaline rocks and carbonatite

To the writer it seems reasonable to postulate that if at one stage in the history of the Kerimasi and Oldonyo L'Engai volcanoes, basement dolomitic limestone in lieu of granitic-gneiss was brought into contact with the parent magma, then a different series of reactions, by a process comparable to "fenitisation" would result, leading to the formation of nepheline rocks and carbonatites. It is suggested the change of position of the basement rocks was brought about by the Sambu faulting, when displacements of 4,000 feet took place.

Compared with other regions where the limestone syntexis process of Daly[1] and his followers has been invoked, the Kerimasi and Oldonyo L'Engai region is somewhat different. Not only is there every possibility that limestone was available, but unlike other carbonatite provinces, once this limestone had been exhausted, the magmatic trend appears to indicate a return to its original state, in this case nephelinitic and phonolitic, suggesting in this region limestone assimilation was a local phenomena of short duration only.

On sketch map fig. 2 is indicated a large belt of dolomitic limestone. As discussed in the section on the basement rocks of this area, this limestone belt was mapped and analysed in several places. The dolomitic limestone runs almost parallel to, and some 70 miles east of, the Oldonyo L'Engai area, whilst further smaller occurrences of dolomitic

(1) Daly R.A. 1933. Igneous rocks and the Depths of the Earth. McGraw-Hill.

limestone, sometimes with graphite-schists, have been noted in the region of step-faulting, very much nearer to Oldonyo L'Engai. One analysis of this limestone did show calcareous rather than dolomitic affinities, but it is considered to be the exception rather than the rule.

No field evidence was found indicating that the belt of limestone dips towards the rift valley, although this may have been the case initially. The smaller occurrences of limestone in the step-faulted area are a more probably limestone source. Future mapping of the outcropping basement to the north and south of the lavas in the Gregory Rift Valley, should provide additional evidence of the possible character of the basement beneath the rift valley lavas.

It seems reasonable to suggest therefore, that a suitable source of dolomitic limestone occurred in the basement rocks, underneath these volcanoes, which was brought into contact with the already modified magma, after a period of major faulting.

The existence of a similar potential source of dolomite is shown to be necessary by von Eckermann[1] who in drawing his PX/TX diagram in explanation of the origin of the Alnö alkaline rocks, found it desirable to postulate the presence of dolomite.

The reaction of the light and heavy fractions of the greatly modified supposed olivine-basalt parent magma, to the dolomitic limestone is now considered, and may be represented thus:-

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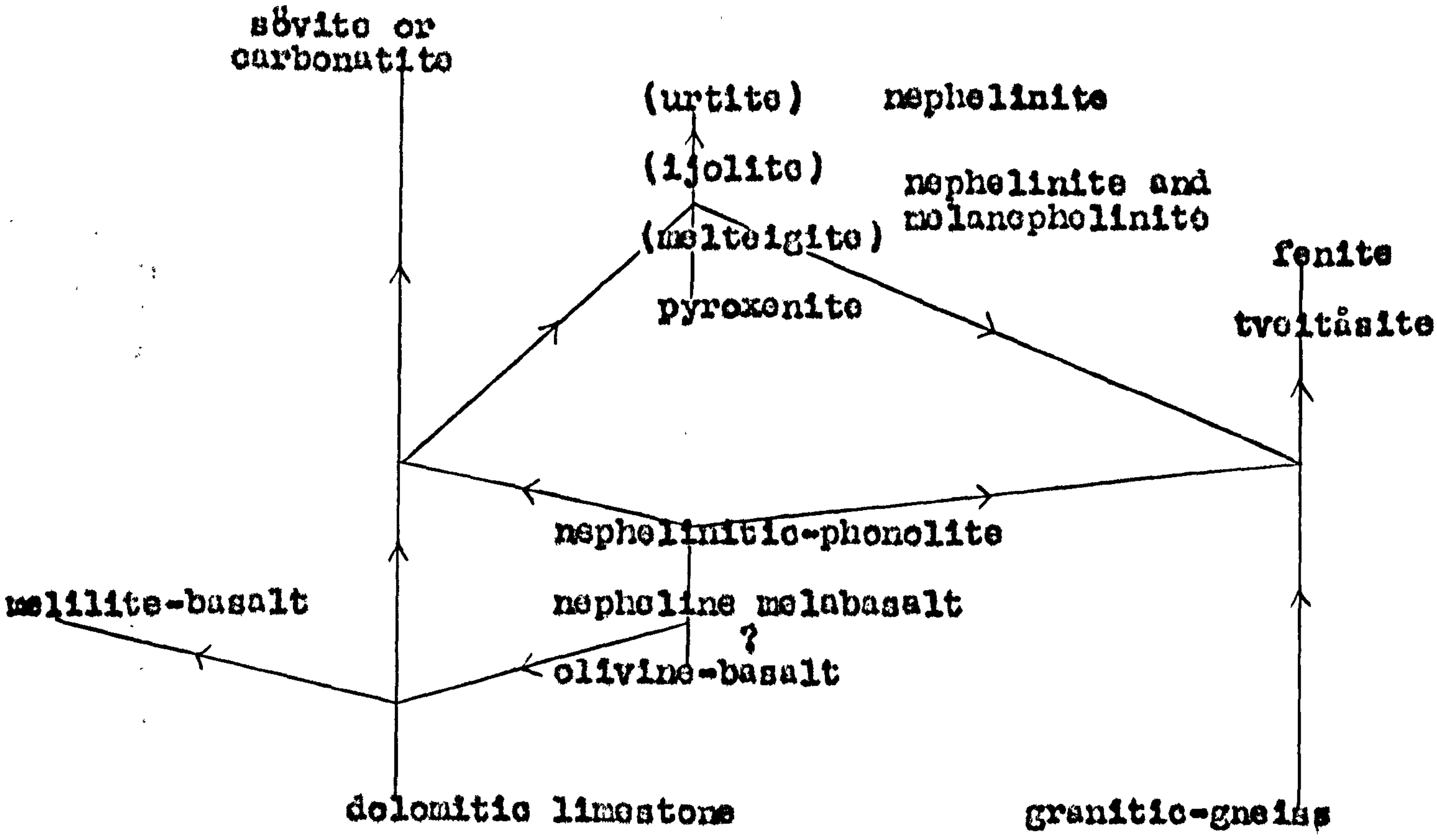
(1) Eckermann H von. 1948. The alkaline district of Alnö island. Sveriges Geologiska Undersokning. Ser. ca. No.36

Magmatic trend - carbonatite, alkaline lava series



No analysis of the nepheline-melabasalt is available, but again using Lehmann's atlantite, which has previously been compared with similar rocks from Hawaii, some comparison can be made, see table No.31, with the new analysis of melilite-basalt from this region. Likewise for the light fraction, two melanephelinites, one from Oldonyo L'Engai and the other from Kerimasi, may be compared, table No. 31, with the more siliceous nephelinitic-phonolite and phonolitic types of this region.

In both cases there is a steep rise in the CaO content, accompanied by rising Fe, MgO, and decreasing Al_2O_3 and alkalis, TiO_2 and P_2O_5 tend to increase at the same time. In the case of the melilite-basalt, however, Fe shows a very slight increase, and the alkalis tend to increase, but, in the biotite-pyroxenite JG1254, already discussed, the alkalis decreased.

The CaO content in all of the three examples of desilicated rocks, JG958, JG1279 and JG808, are higher than any CaO content noted by MacDonald[1] in his series of average analyses of the Hawaiian rocks. Compare 13.70% CaO of the average Hawaiian melilite-basalt, with 14.43% the lowest figure for CaO in the three

(1) MacDonald G.A. Hawaiian petrographic province. Amer. Geol. Soc. Vol. 60 pp. 1541-1595.

TABLE NO.31

Analyses of Certain Rocks Pre- and Post- Desilication

	J0953	No.1	J01279	J0808	J0866	J0923
SiO_2	34.46	42.96	43.03	45.59	48.67	57.34
Al_2O_3	9.18	14.95	13.01	10.40	10.53	20.55
Fe_2O_3	6.10	6.24	2.40	5.04	4.23	1.92
FeO	8.77	7.58	5.42	8.10	2.07	3.06
MgO	9.83	7.68	7.40	8.51	.98	.78
CaO	16.55	11.77	14.43	15.06	5.44	2.23
Na_2O	4.46	3.65	5.88	5.80	9.36	7.39
K_2O	2.52	1.43	2.13	1.78	3.88	3.88
H_2O +	.63	.57	.52	.40	1.85	1.56
H_2O -	.57	.28	.14	.15	1.68	.54
CO_2	.02	-	-	-	2.02	tr
TiO_2	4.05	2.10	2.76	.89	.64	.31
P_2O_5	1.26	1.00	.51	.46	.23	tr
MnO	.24	n.d	.44	.23	.18	.46
	100.23	100.21	99.86	100.22	100.01	99.72

J0953 Melilite-basalt, Armykon Hill, North of Oldonyo L'Engai. Analyst. W.H.Herdsman.

No.1 Atlantite, Rungwe, E. Africa, Byme Analyst.

J01279 Melanephelinite, Oldonyo L'Engai, Analyst W.H.Herdsman.

J0808 Melanephelinite, Kerimasi, Analyst, R.O.Roberts.

J0866 Nephelinitic-Phonolite, Oldonyo L'Engai, Analyst W.H.Herdsman.

J0923 Phonolitic-Trachyte, Gelai, Analyst W.H.Herdsman.

rocks quoted above or 12.02% the lowest CaO figure in JG818, the pyroxene-amphibolite, for any of the Kerimasi-Oldonyo L'Engai rocks.

It has been mentioned that MacDonald[1] having formed his undersaturated rocks by methods other than the assimiliation of limestone suggests that limestone assimilation "would furnish a ready explanation for the distinctly higher content of lime in these lavas as compared with the parent olivine-basalt" (which at Hawaii, contains 10.34% CaO).

MacDonald has shown how to derive all the Hawaiian rocks by a well reasoned account in which he indicates the quantities and minerals necessary to be added to or subtracted from the parent magma. Some years before Larsen[2] describing the Iron Hill alkaline complex of Colorado used a similar line of approach. Although essentially theorectical this could equally well be applied to the alkaline petrographic province under consideration.

The melilite-basalt

This rock is to be found as a large lava flow on the northern flanks of Oldonyo L'Engai, with other smaller occurrences slightly to the north; of these the small hill called Armykon is particularly important. From the position of this lava on the flank of Oldonyo L'Engai, it is certainly one of the oldest, if not the olders flow of lava on the mountain. It has been noted before how MacDonald[1] derives the melilite-nepheline-basalts of Hawaii, and his suggestion that lime assimilation would explain the high CaO content.

Elsewhere in the same work MacDonald maintains that "the addition of a larger amount of lime in some magma chambers, either as sunken plagioclase, or by the assimilation of limestone, may lead to the local development of melilite

(1) MacDonald G.A. Hawaiian petrographic province. Amer.Geol. Soc. Vol. 60 pp. 1541-1595.
(2) Larsen E.S. 1942 Alkalic rocks of Iron Hill, Gunnison County, Colorado U.S. Geol. Soc. Prof. Paper 197-A.

rocks".

From the analyses quoted above it is suggested that in the Oldonyo L'Engai area the possibility of limestone assimilation may have been greater than MacDonald[1] thought to be possible in the case of Hawaii.

At the Iron Hill alkaline complex, Larsen[2] derived his uncompahgrite rock, from one of Daly's average plateau basalts by assimilation of limestone - strictly dolomite at depth.

Melilite-bearing rocks have been described from a number of places in East Africa; in 1934 Finckh[3] noted rocks containing melilite and leucite from Goma, while other occurrences have been noted by Holmes and Harwood[4] in the Bufumbira region; by Odman[5] on Mount Elgon, and more recently by King[6] from the Napak area, all in Uganda. Melilite-basalt has also been reported[7] from Kilimanjaro. The presence of melilite-basalt in the Oldonyo L'Engai region is not exceptional, and in this case at least, but perhaps not to the same extent in some of the other occurrences, the modified parent magma has most probably been still further desilicated by the assimilation of dolomitic limestone.

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(1) MacDonald G.A. Hawaiian petrographic province. Amer. Geol. Soc. Vol. 60 pp. 1541-1595.
(2) Larsen E.S. 1942. Alkalic rocks of Iron Hill, Gunnison Country, Colorado U.S.Geol. Soc. Prof. Paper 197-A.
(3) Finckh L. Die Jungvulkanischen Gesteine des Kiwusee-Gebietes Wiss. Ergebn. Deutsch. Zentral Afrika Exped. 1907-1908. Bd.1. (1) pp.44.
(4) Holmes A & Harwood H.F. 1937. The volcanic area of Bufumbira. Geol. Surv. of Uganda. Memoir III.
(5) Odman O.H. 1930. Volcanic Rocks of Mt. Elgon in British East Africa. Geol. Föreningens Förhandlingar 1930 pp. 455-537.
(6) King B.C. 1949 The Napak area of Southern Karamoja Uganda Geological Survey, Memoir V.
(7) Klute F. 1912. Der Kilimanjaro quotes Finckh.

The carbonatites

It is considered probable that Kerimasi was formed while the desilication of the magma was in progress. This volcano consists essentially of calcareous and alkaline rocks in the form of ejected fragments, which include boulders of carbonatite; all are representatives of a highly explosive light magmatic fraction, charged with CO_2 due to the dissociation of the dolomite.

Two analyses only have so far been made of the Kerimasi carbonatites, but they are instructive, and compare with sövites or carbonatities from other parts of the world. One of the Kerimasi rocks JC823 contains 51.66% CaO, the main "impurities" are Fe and P_2O_5. The second carbonatite JC810 shows 38.01% CaO, but contains over 11% of both Fe_2O_3 and MgO; these are present in the minerals forsterite and magnetite, the former generally accepted as being formed through the metamorphism of dolomite. In the case of the rock JC810, forsterite is accompanied by spinel, which Harker[1] maintains is "a very characteristic accessory mineral in forsterite and diopside-marbles". In both of these rocks Deans has found baddeleyite, which he regards as a mineral peculiar to carbonatites - a conclusion with which the writer agrees. Some attention has previously been paid to the abundance of sphene, perovskite, melanite and apatite, in many of the Kerimasi and Oldonyo L'Engai rocks. These minerals indicate high TiO_2 and P_2O_5 content, which are features of carbonatite and their associated alkaline rocks as a whole.

To the writer therefore, in the light of present knowledge, there is little doubt that these Kerimasi calc-rich rock fragments are carbonatites or sövites, and that they have originated from the metamorphism perhaps accompanied

(1) Harker A. 1939 Metamorphism. Methuen 2nd Edition.

by mobilization of the basement dolomitic limestone. They carry both dolomitic metamorphic minerals, and a suite of minerals typical of carbonatites containing P_2O_5, TiO_2 and ZrO_2, which are assumed to have been introduced by some hydrothermal process from a deep-seated magmatic source.

Probably contemporaneous with the formation of Kerimasi, are the small subsidiary calcareous ash cones like Mamota, possibly Kisetoy, and no doubt the large explosion crater of Embagai.

The magmatic trend after the carbonatite formation

It has already been mentioned that Mosonik was being formed of nephelinitic and nephelinitic-phonolitic rocks before the last major period of faulting, when the Sambu fault was formed, as some of the lava flows from Mosonik have been faulted. As a result, the rocks of this mountain hav e been taken to be indicative of the magma at the period of desilication. No rocks of the urtite-melteigite nephelinite type were found on Mosonik.

It is interesting to note that the nephelinitic-phonolitic magma suggested as being the state of the parent magma prior to major desilication, is represented in the more phonolitic lavas amongst the latest extrusions of Kibo, the nepheline-syenite plug on Mount Kenya, and the phonolites which were collected from Mount Meru.

Further, the rock JG866 collected from what is one of the highest, and therefore possibly, youngest lava flows on Oldonyo L'Engai, shows on chemical analysis to be comparable with the partial analysis of JG965 from Mosonik an example of one of the older predesilication rocks. It was recorded by Hobley[1] that lava flows were reported from Oldonyo L'Engai during the 1917 eruption, and the volcano has erupted several times since that date.

(1) Hobley C.W. 1918. A volcanic eruption in E.Africa. Journ. E. African Nat. Hist. Soc. VI.

The table 26 stresses the large number of comparable specimens of nephelinitic-phonolites from Oldony L'Engai and Kosonik.

It is suggested that the formation of Kerimasi was a special phase in the petrogenetic history of the submagma, which after extensive desilication, metamorphism and metasomatism, leading to the explosive extrusion of the carbonatites and soda-rich alkaline rocks, tended to return to the more normal phonolitic conditions, after the available dolomitic limestone was largely exhausted.

The urtite-melteigite types of nephelinite and the biotite-pyroxenites

So far no mention has been made of the above suite of rocks, which like the carbonatites, have been found only as ejected fragments.

All of these rocks are typical of alkaline provinces, and have been discussed at some length in the literature. It is believed that the action of a magma of nephelinitic-phonolitic composition on dolomitic limestone would result in the formation of carbonatite, and a new alkaline magma, which on differentiation by crystal settling,would account for the leucocratic to melanocratic series of nephelinites, likened to the urtite-melteigite series, and the ultra-basic biotite-pyroxenite. These ultra-basic rocks must have been formed by crystal accumulation in a deep-seated magma. The main differentiation process outlined above would be considerably modified by metasomatic effects borne out by the presence of sulphides, apatite and titanium-bearing minerals. A relatively large number of blocks of melanephelinite with melteigite affinities were collected on the summit of Oldonyo L'Engai and are suggestive of recent origin. They may perhaps be referred to the 1940-41 eruption; although no such rocks are described in detail by Richard[1].

(1) Richard J.J. 1942 Volcanological Observations in East Africa - Oldonyo L'Engai. The 1940-41 eruption. Jour. E.African Nat. Hist. Soc. Vol. XVI. No.2 & 3 (71 & 72) pp. 89-108.

If this is the case it appears to indicate that the phonolitic magma has more recently become desilicated to a certain extent. Detailed microscopical investigation on the lines of Dr.Pulfrey's work on the Homa Bay alkaline rocks would probably indicate further magmatic cycles.

Variation diagrams

These have been compiled for the Oldonyo L'Engai suite of rocks, the Kerimasi ejected lava blocks and the Kerimasi carbonatites. All known chemical analyses for these two volcanoes have been incorporated: details of these analyses will be found in tables No. 32 and 33.

1. The Oldonyo L'Engai variation diagram

The most interesting features about this variation diagram are the irregularities between 42% and 44% SiO_2. They occur in an otherwise reasonably normal set of curves, which are generally taken as suggesting that a suite of rocks has originated by magmatic differentiation and crystal settling processes.

Although such differentiation processes have been postulated in the discussion on petrogenesis above, it has been shown that these processes were considerably modified at times, and it is suggested that the true magmatic cycle cannot be clearly followed from one set of curves plotted irrespective of the time factor. This is because the postulated nephelinitic-phonolite magma apparently underwent modification through assimilating a limited amount of dolomite, eventually returning to its original composition; presumably when the supply of dolomitic limestone became exhausted. Nevertheless, such diagrams serve to stress certain significant points which are now considered in some detail.

It was also suggested that the magma at the commencement of the formation of Oldonyo L'Engai, was a nephelinitic-phonolite of chemical composition like the rock JG965, see table 30 from the older mountain of Mosonik, which was

(1) Pulfrey W. 1950. Ijolitic rocks near Homa Bay. Western Kenya. Q.J.G.S. Vol. CV. pp. 425-459.

TABLE NO.32

Chemical Analyses, Oldonyo L'Engai, Gelai and Kibangaini

	JG958	JG1275	L7	L11	No.1	JG836	JG1270	JG866	JG894	JG923	JG1145
SiO_2	34.46	37.13	39.66	42.44	43.04	43.15	43.93	48.67	53.35	57.34	62.90
Al_2O_3	9.18	12.11	11.49	12.20	15.04	16.65	13.84	18.53	19.96	20.55	14.09
Fe_2O_3	6.10	7.25	6.70	8.35	4.15	6.50	2.40	4.28	3.29	1.92	6.26
FeO	8.77	3.45	3.56	3.14	2.78	1.43	8.42	2.07	2.37	3.06	1.77
MgO	9.83	4.27	1.90	1.03	2.17	.87	7.40	.98	.79	.78	.51
CaO	16.55	19.34	17.54	10.73	19.05	9.10	14.43	5.44	3.12	2.23	1.98
Na_2O	4.45	6.15	7.84	14.24	7.61	9.20	5.83	9.56	9.48	7.39	6.25
K_2O	2.52	2.54	3.52	5.19	3.49	4.30	2.13	3.88	4.46	3.58	4.05
H_2O +	.63	.26	.30	.19	-	-	.52	1.85	1.00	1.50	.30
H_2O -	.57	.12	1.31	.46	.84	1.23	.14	1.08	.52	.54	.17
CO_2	.32	-	2.54	.50	.84	-	Nil	2.02	tr	tr	-
TiO_2	4.85	3.93	2.01	2.15	.94	1.30	2.76	.64	.07	.31	.76
P_2O_5	1.26	2.82	1.03	.60	.49	-	.51	.23	.08	tr	.67
MnO	.24	.20	.33	.34	-	.03	.44	.18	.42	.40	.16
S	-	-	.28	-	-	-	-	-	-	-	-
F	-	-	.43	.20	-	.35	-	-	-	-	-
BaO	-	-	-	-	-	.08	-	-	-	-	-
SO_3	-	-	-	-	-	.14	-	-	-	-	-
Cl_2	-	-	-	-	-	.05	-	-	-	-	-
	100.25	99.54	100.44	99.82	100.42	(94.38)	99.86	100.01	99.87	99.72	100.19
Less O_2			.18	.12							
			100.26	99.70							

JG 958 Melilite-basalt, Armykon Hill, North of Oldonyo L'Engai, Analyst. W.H.Herdsman.
JG1275 Melanephelinite, Oldonyo L'Engai. Analyst. R.O.Roberts.
L.7 Nephelinite, Oldonyo L'Engai, Collected by J.J.Richard, analyst. Miss [illegible].F.R.Hitchens.
L.11 Nephelinite, Oldonyo L'Engai, Collected by J.J.Richard, analyst. Miss [illegible].F.R.Hitchens.
No.1 Erdmannsdorffer's Wollastonite-Ijolite, N. Foot of Oldonyo L'Engai, Analyst [illegible].
JG 836 Partial Analysis only Nephelinitic-Phonolite, Oldonyo L'Engai, Analyst, Dept. of Glass Technology, Sheffield University.
JG1270 Melanephelinite, Oldonyo L'Engai, Analyst, W.H.Herdsman.
JG 866 Nephelinitic-Phonolite, Oldonyo L'Engai, Analyst W.H.Herdsman.
JG 894 Nephelinitic-Phonolite, Oldonyo L'Engai, Analyst W.H.Herdsman.
JG 923 Phonolitic-Trachyte, Gelai, Analyst. W.H.Herdsman.
JG1145 Riebeckite-Trachyte, Kibangaini, Analyst. C.V.Green.

TABLE NO. 33

Chemical Analyses, Korimasi

	No.1	JG818	JG1254	JG808
SiO_2	39.26	39.72	41.38	45.59
Al_2O_3	15.75	8.53	9.51	10.46
Fe_2O_3	4.08	8.05	6.90	5.04
FeO	3.14	7.42	8.37	5.19
MgO	3.62	11.44	12.40	8.51
CaO	16.69	12.93	16.62	15.66
Na_2O	7.50	2.25	.93	5.80
K_2O	3.03	.98	1.12	1.78
H_2O +	.94	1.09	.58	.46
H_2O -		.40	.32	.15
CO_2	-	-	Nil	-
TiO_2	1.66	7.03	1.20	.69
P_2O_5	3.28	.04	.43	.46
MnO	n.d	.17	.41	.23
	99.83	100.15	100.08	100.22

No.1 Melanite-Ijolite, Analyst Byme.

JG818 Pyroxene-Amphibolite, Kisotey, Analyst, W.H.Herdsman.

JG1254 Biotite-Pyroxenite, Analyst W.H.Herdsman.

JG808 Melanephelinite, Analyst R.O.Roberts.

being formed before the last great period of rift faulting. This rock is very similar to JG866, one of the more recent lava flows from the younger volcano. The slightly more siliceous rock JG894 was not found in situ, but most certainly comes from Oldonyo L'Engai.

The variation diagram should show further differentiation of this nephelinitic-phonolite magma, (the modified regional parent magma) also any special effects, such as the assimilation of limestone, should perhaps be indicated by both the modified nephelinitic-phonolite and the heavier crystal accumulated portion of the same magma.

It will be noticed on the variation diagram that, as the silica percentage decreases to just under 44% SiO_2, the CaO and MgO increase noticeably, while both alkalis decrease. This is where there is a very marked CaO-MgO peak in the variation diagram. With a decrease of less than .8% SiO_2 from this point, the CaO now decreases rapidly, while with a further reduction of just over .1% of SiO_2, the CaO once again increases by almost 10% to a total of 19.03% of CaO in the wollastonite-ijolite quoted by Erdmannsdorffer[1]. In a further decrease of just over .5% of SiO_2 to 42.44% SiO_2, the CaO decreases rapidly once more, to just over 10%. No other peaks occur towards the low silica end of the diagram, although the analysis of JG1275 a melanephelinite, causes a small rise in the CaO value.

Up to this point CaO and MgO have moved sympathetically, accompanied by TiO_2, whilst Al_2O_3 and the alkalis have been antipathetic to them. Generally the FeO and Fe_2O_3 tend to be sympathetic to CaO and MgO, but this does not follow in every case.

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(1) Erdmannsdorffer O.H. 1935. Uber Wollastoniturtit und die Enststehungsweisen von Alkaligesteinen. Sitzungsberichte der Heidelberger Akademie der Wissenschaften. Maths.Kl.

A further decrease in SiO_2 below 42.44% shows a break-down in the above relationship. Now, the CaO, Al_2O_3 and Na_2O decrease, whilst MgO, FeO and TiO_2 increase relatively considerably. This change in the relationships of the sympathetic and antipathetic oxides is interpreted in the following manner. At about 37% SiO_2 the normal crystallization differentiation process, with modifications ceases, and the origin of the most basic rock, the melilite-basalt, JG958 must be accounted for by some other means. The process which has been suggested is the desilication of the heavy fraction of the modified parent magma, together with some crystal accumulation as witnessed by the presence of olivine in these melilite-basalts.

The variation curve of the Oldonyo L'Engai rocks, therefore, substantiates the hypothesis that a normal differentiation series of the nephelinitic-phonolitic magma existed, and is represented by the rocks JG866, JG836, L11 and L7, more phonolitic varieties to more melanephelinitic varieties. Superimposed on this normal variation diagram are the effects of another abnormal differentiated magmatic series, represented by the calc-rich extrusive equivalents of the urtite-melteigite-biotite-pyroxenite magma. These are shown in the variation diagram by analyses of JG1275, a melanephelinite with melteigite affinities, the wollastonite-ijolite of Erdmannsdorffer,[1] and JG1279 another melanephelinite but resembling the more leucocratic ijolites.

If these calc-rich rocks were ommitted, the variation diagram would have a more normal appearance, as indicated in fig. 9 , by the dotted line curve for the undesilicated rocks.

There would appear to be no great distortion of the variation diagram, caused through joining the more siliceous end of the variation diagram of the Oldonyo L'Engai rocks, that is JG894, with the Gelai phonolitic-trachyte, which itself

(1) Erdmannsdorffer O.H. 1935. Uber Wollastoniturtit und die Entstehungsweisen von Alkaligesteinen. Sitzungsberichte der Heidelberger Akademie der Wissenschaften. Maths Kl.

has been joined to the Kibangaini trachyte. It has been suggested all these rocks are representatives of a regional magamtic trend, and in fact, the resulting composite variation diagram resembles part of Prior's[1] variation diagram see fig. 10, on a suite of volcanic rocks from Kenya, which however are generally very much more siliceous than the rocks from the area now under consideration.

2. <u>The Kerimasi variation diagram</u>

The three known analyses from this volcano of rocks other than carbonatites, have been plotted on a variation diagram, which in spite of the small number of analyses available, indicates some interesting features worthy of further comment.

When the Kerimasi variation diagram is compared with the variation diagram of the Oldonyo L'Engai rocks, the noticeable feature is the extremely high CaO content of the Kerimasi rocks. The highest figure for CaO occurs at 41.35% SiO_2. It will be seen that, taking no notice of the influence of JG818 from Kisetey, for the time being, CaO is followed sympathetically by MgO, Fe_2O_3 and FeO, whereas, as noted in the Oldonyo L'Engai diagram, the Al_2O_3 and alkalis are once again antipathetic. This suggests that the rocks used in the construction of this diagram, are allied in composition to the extrusive equivalents of an urtite-ijolite-melteigite magma; in all probability, the same magma noted above in the explanation of the Oldonyo L'Engai variation diagram.

There are no peaks in the Kerimasi variation diagram, until the rock JG818 from the parasitic cone Kisetey is considered. This rock is the pyroxene-amphibolite previously ascribed see p.71, to be a most uncommon, and rather unusual altered type of pyroxenite. The CaO value now decreases towards JG818 as does the MgO, Al_2O_3 and K_2O, whilst both FeO and Fe_2O_3 and Na_2O rise, along with TiO_2; the latter showing

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(1) Prior G.T. 1903 Min. Mag. Vol. XIII p.247
Harker A 1909. The natural history of igneous rocks. Methuen.

a rather spectactular increase at this point. These anomalous conditions, as previously noted in the case of the melilite-basalt of Oldonyo L'Engai, point to an origin for this rock other than the normal crystal accumulation process invoked previously. The high TiO_2 and the presence of (OH) in the amphibole are suggestive of considerable modifications by hydrothermal processes.

3. The carbonatite variation diagram

It is interesting to note that when the two analyses of carbonatite are taken into consideration, one a pure and the other an impure variety, then, as the CaO and P_2O_5 increase, the Fe_2O_3 and MgO decrease, while the FeO remains much the same. This is a different state of affairs compared with the variation diagrams shown to be representative of magmatic differentiation, and therefore, the carbonatites would appear to have been formed under special conditions.

General Conclusion

It is suggested that this petrographic province throws new light on the formation of carbonatites. In Kerimasi, the carbonatite is found as ejected blocks, although it may well occur in the throat of the volcano, as is the case in other localities. Secondly, the carbonatites are not the last rocks to be formed in this region, as Oldonyo L'Engai is active, producing nephelinitic and phonolitic types.

The writer has endeavoured to demonstrate that the modification of a light fraction nephelinitic-phonolitic type of magma, which is extremely common in East Africa, may have resulted from differentiation and some alteration by contamination with the country rock from an olivine-basalt parent magma. This nephelinitic-phonolitic magma type, after a period of major faulting, has subsequently been further desilicated, through the assimilation of a limited supply of dolomitic limestone from the basement complex, resulting inthe formation of melteigite types of of melanephelinite and associated rocks, and carbonatite. After the limestone supply had been largely exhausted, the magma reverted to its original more phonolitic nature, with further, possible evidence of a period of more recent desilification. The heavy fraction of the modified original magma, was also desilicated to account for the mellilite-basalts.

It is fully appreciated that the above hypothesis will be modified in the light of future, more detailed investigations; the present thesis, it is stressed, results from geological reconnaissance only.

The relationship of Kerimasi to the other carbonatites of East and Central Africa

In conclusion, brief notes are submitted on some of the wider aspects of the significance of this small area of volcanic rocks just described. Attention is directed to certain existing anomalies resulting from the arguments put forward in the above work.

1. The belt of dolomitic limestone has been demonstrated to pass in all probability, underneath the lavas of Mount Meru and part of the Kilimanjaro massif, yet no mention has been made of carbonatites in this area.

At the time of writing, the answer to this question is simply that insufficient work has been done in the Mount Meru - Kilimanjaro area, which up to now, shows little sign of any carbonatite rock.

Some rocks which may possibly be interpreted as products of desilication by a assimilation of limestone have been found on Mount Meru and the Kilimanjaro massif. For instance, Lacroix[1] has reported ijolite rocks from Kilimanjaro. Analyses of the rhomb-porphyries from Kibo have been mentioned in the section on petrogenesis, see p. 151 and table 30, but these rocks show low CaO content and are relatively rich in alkalis. They have been compared with the light fraction of nephelinitic-phonolite before the major desilication episode. However, melilite-basalt considered in the case of Oldonyo L'Engai to have been formed largely by the assimilation of limestone has also been reported from (L.Chala) Kilimanjaro[2] Similar rocks however have been noted at Hawaii, where there is no

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(1) Lacroix 1906 Sur quelques roches ijolithiques du Kilimanjaro. Bull. Soc. Fr. de Min XXIX pp.90-97.

(2) Klute 1912 Der Kilimanjaro.

outcropping carbonatite. MacDonald[1] has suggested that assimilation by limestone could have been possible in the case of the mellilite-basalt from Hawaii, and would, in fact, have been theoreotically desirable.

Much more detailed work is required in this area before any conclusions can be made. It is perhaps significant to note that as anticipated in the formation of carbonatites, the contaminated magma would initially be highly explosive in nature due to the CO_2 content, as suggested by Tomkeieff[2] in 1938. This is borne out by Kerimasi, a young volcano, probably post-Upper-Pleistocene in age which as yet shows no appreciable carbonatite core, but is a volcano made up essentially of fragments of limestone.

At a late period in the formation of Mount Meru there must have been a tremendous volcanic explosion, which blew away part of the eastern face of the mountain from the summit, 14,978 feet to a height of about 9,000 feet. These disrupted blocks of lava can now be seen scattered over the plains between Meru and Kilimanjaro, where they have blocked the old drainage system to such an extent, that on these plains ponded drainage is to be seen in place of river courses. The whole region requires very thorough and careful investigation.

To the north of these two great volcanic piles, at the junction of lava and basement, one of the samples collected as dolomitic limestone, was found on chemical analysis to be deficient in MgO, and the analysis resembles that of some of the carbonatites. No explanation can be offered for this apparent anomaly at this stage, although non-dolomitic basement limestone is known in Africa.

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(1) MacDonald G.A. Hawaiian petrographic province. Amer. Geol. Soc. Vol. 60 pp. 1541-1595.
(2) Tomkeieff S.I. 1938. The rock of CO_2 in Igneous magma. Rep. Brit. Assoc. p.417.

In the discussion of Dr.Pulfrey's[1] recent work on the "Ijolitic rocks near Homa Bay, West Kenya", Prof. Shand drew attention to the well known "series of ijolitic instrusions which extended from Sekukuniland, in the eastern Transvaal, through Rhodesia, Portuguese East Africa, Nyasaland, Tanganyika, Uganda to Kenya", and in the same discussion Dr.C.S.Hitchen said as far as he was aware, "no carbonatites had been reported from Tanganyik that might line up with the occurrences mentioned, and that caused a rather big gap in the supposed belt or zone. Nevertheless a north-south control of these interesting intrusions did seem to be apparent, though the occurrences might, possibly, be more readily referred to several parallel or sub-parallel lines. On the eastern side of the Kenya Rift, for example, there was a series of dunite pipes also arranged on a north-and-south line.....It would seem that the magmas or emanations responsible for these various intrusions had arisen from great depths and had possibly been controlled by the general north-and-south grain of the Basement Complex".

In the same discussion Dr.A.W.Groves drew attention to "yet another ijolite in Kenya that had not been mentioned that evening, namely Mount Jombo, intrusive into the Triassic of the coastal belt".

When the writer read the above paper and discussion he realised the possible importance of Kerimasi in helping to fill in the above gap. This knowledge precipitated the wish to study the interesting suite of volcanic rocks of this region, in more detail than would have been possible in the normal course of duties in Tanganyika.

In describing the work done in this area by the Germans and other workers, see pp. 49, it was stated that in 1921 Brogger[2] noted "sovite" from Kerimasi and Mosonik, and

(1) Pulfrey W. 1950. Ijolitic rocks near Homa Bay. Western Kenya.
(2) Brogger W.C. 1921. Die Eruptivgesteine Des Kristiania-gebeites.

alkaline rocks from Oldonyo L'Engai and Shombole. The writer found no carbonatite at all from Mosonik. More recently, 1952, phosphatic limestone possibly associated with the volcano of Ufiomo was being investigated as probable carbonatite. This volcano lies just over 100 miles due south of Kerimasi.

The map fig. 12 , show that Kerimasi does not materially help to fill the gap in the initial north-south line of carbonatites, but the map does show, however, that in Southern Rhodesia and Transvaal, the carbonatites occur to the west of the north-south line approximately the 35° east meridian, and in Transvaal, if they have any orientation at all, it is ENE.

A possible carbonatite has recently been located in Northern Rhodesia(1) near Isoka, which is also to the west of the main north-south line. The Jombo occurrence and Kerimasi both occur to the east of this line.

It would perhaps be more correct to state that the East and Central African carbonatites appear to be associated with the rift faulting, which does run north-south, but are not necessarily associated with the western or any other rift valley. They may occur in the eastern Gregory Rift Valley, and appear to be connected with similar types of faulting to be found along the East African coast. All of these regions it is felt, should be examined for further occurrences of carbonatites.

(1) Colonial Geology and Min. Res. Vol. 2. No.4 1951. p.320.

1.

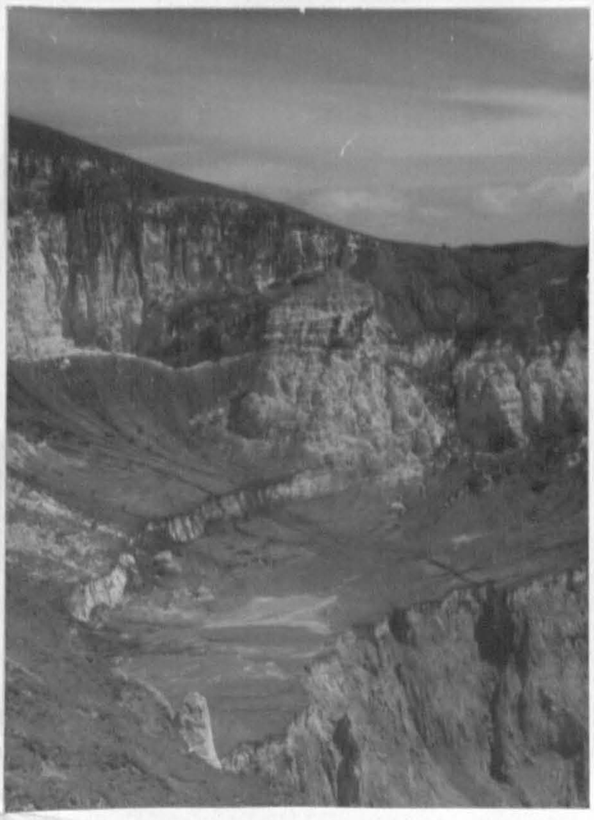
East flank of Oldonyo L'Engai, showing white soda deposit near the summit region.

2.

West flank of Oldonyo L'Engai, dotted line shows route of ascent by writer in 1950 and 1951.

3.

Ash crater between Kerimasi and Oldonyo L'Engai.



4.

The explosion crater of Oldonyo L'Engai, composed mainly of ash and tuff with much superficial white soda.

5.

The explosion crater of Oldonyo L'Engai, looking north.

6.

Yellow agglomerate of Oldonyo L'Engai in R. Sinyalandaray, between Kerimasi and Oldonyo L'Engai.

7.
Kerimasi, showing the ejectamenta spreading over the rift wall to the west. The photograph was taken from the summit of Oldonyo L'Engai, and shows part of the old crater in the foreground.

8.
The rift wall in the neighbourhood of Engaruka, taken from the south flank of Kerimasi. The Winter Hochland to the west.

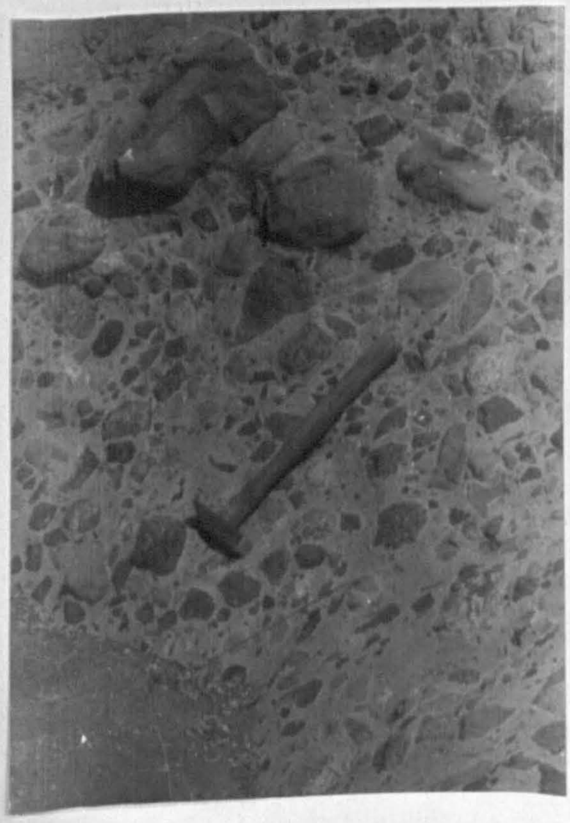
9.
The NE flank of Kerimasi, notice the possible outcropping rock, ? carbonatite, about half-way towards the summit.

10.

The NE flank of Kerimasi, Field Assistant D.J.Nyirenda and boulders of carbonatite.

11.

Large carbonatite boulders in dry river course on the NE flank of Kerimasi.



12.

Volcanic agglomerate, forming small bluff on the S flank of Kerimasi.

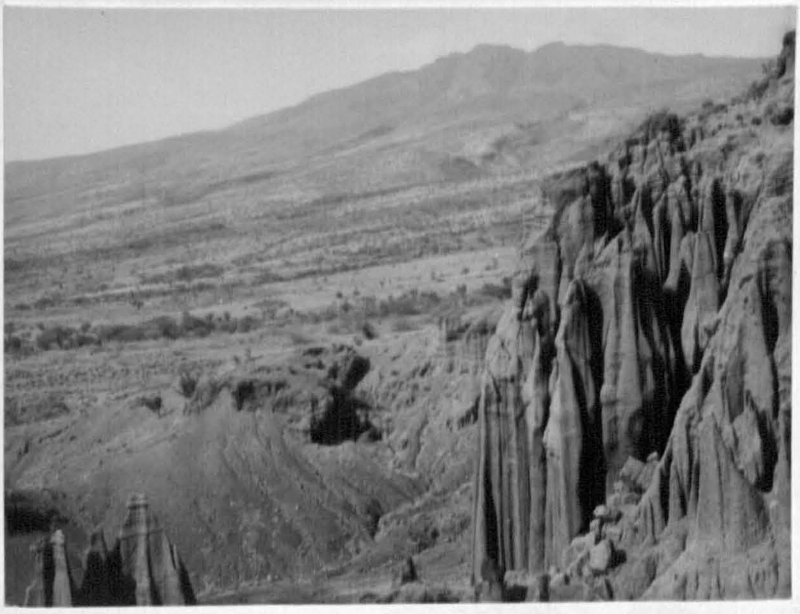
13.

Weathered carbonatite in calc-tuff on SE flank of Kerimasi.

14.
Shombole and the north end of
Lake Natron, looking eastwards.

15.
The northern flank of Mosonik,
photo taken above the rift scarp.

16.
Ketumbaine looking eastwards from
Kerimasi.



17.

West flank of Gelai, in foreground eroded cone of "basaltic" ash.

18.

NW flank of Gelai, showing scores of small volcanic craters and Lalarasi in the foreground.

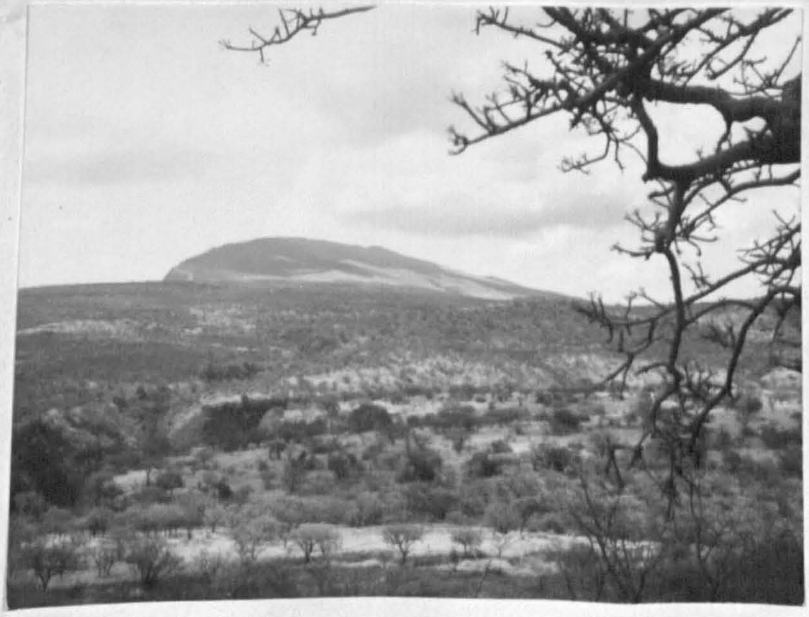
19.

"Basaltic" type of lava from Gelai, exhibiting good spheroidal weathering.

20.

Lake Natron in the distance from the step-faulted area to the east.

21.
Lake Natron, looking west towards Oldonyo Sambu, the small Losideti hills are on the right.



22.
Oldonyo Sambu from above the rift wall.

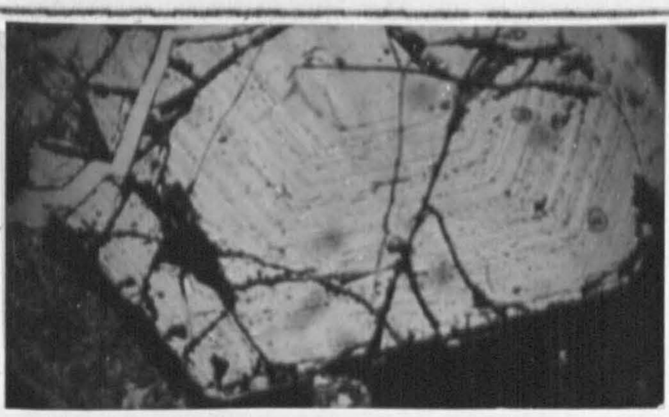
23.

Basement quartzite, disturbed by the activity of the Oldonyo Sambu volcano.

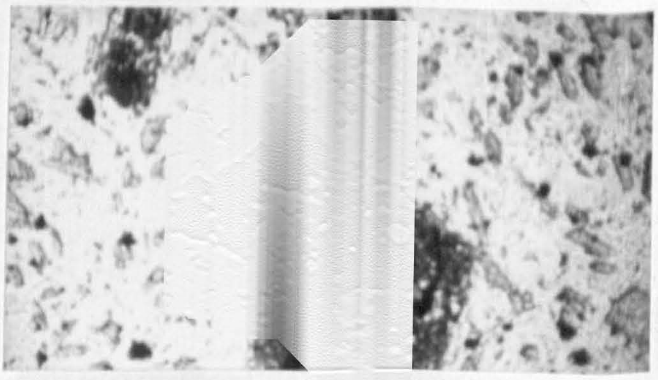
24.
Lava flows between yellow lake beds in the Malambo area.

25.
Western escarpment of the Gregory rift valley in the Engaruka region.

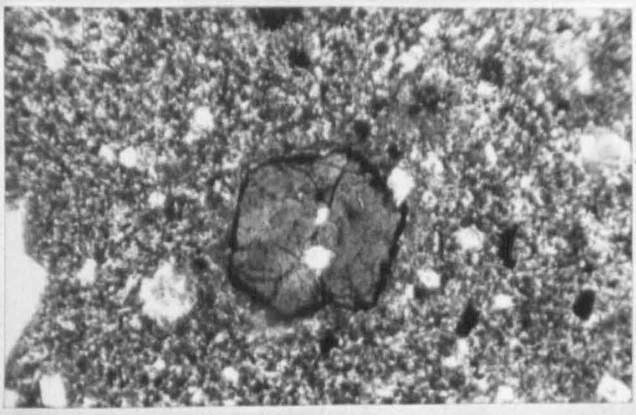
Photomicrographs of some of the younger and older extrusive rocks of the Engaruka - Oldonyo L'Engai - Lake Natron area of Tanganyika Territory.



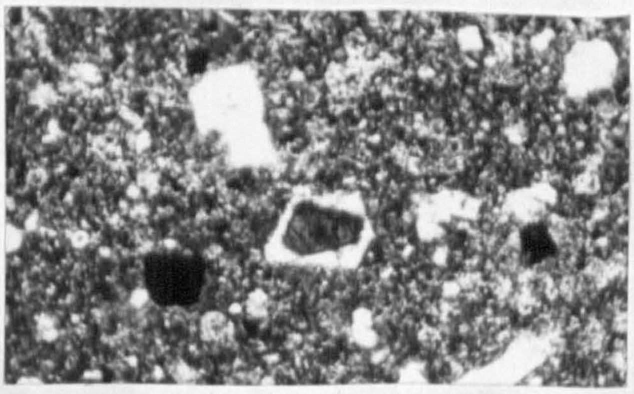
JG772(2) Nephelinite from Embagai. Ord.light. X 28. To show zoning in a large nepheline crystal.



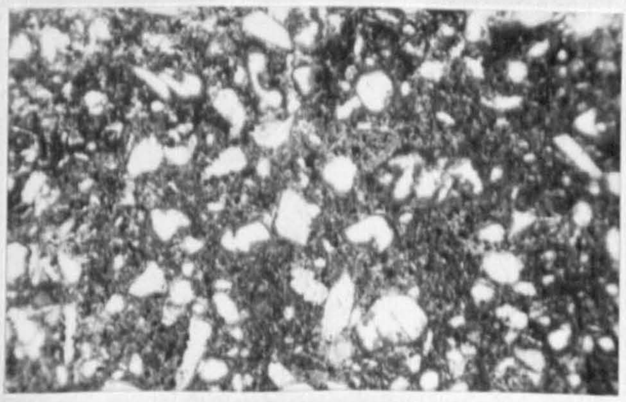
JG782 Andesitic type. Rift wall S of Engaruka. Ord. light. X 28. Resorption borders around hornblende crystals.



JG800 Nephelinitic-phonolite, Ketumbaine. Ord. light. X 88. Olivine enclosing nepheline.

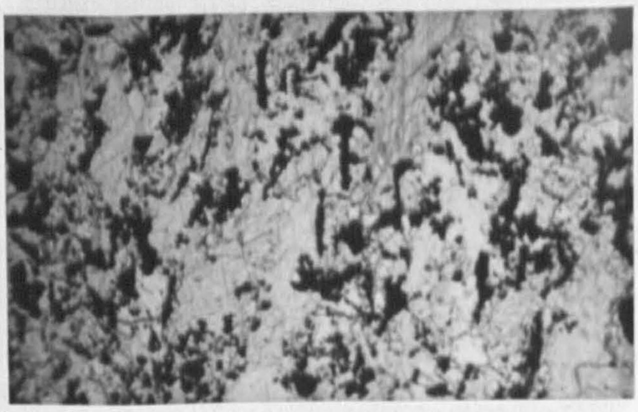


JG800 Nephelinitic-phonolite, Ketumbaine. Ord. light. X 88. Nepheline enclosing olivine.



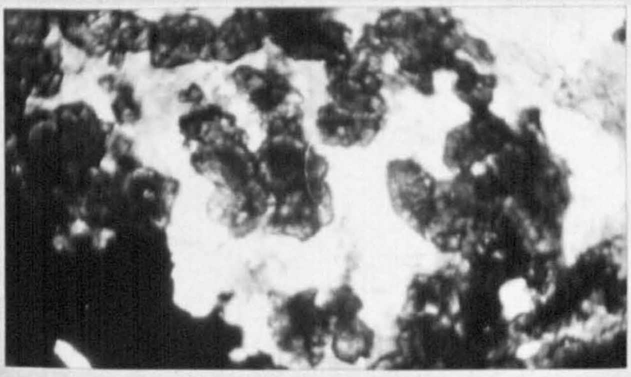
JG802 Olivine-rich andesitic type. Ketumbaine. Ord.light. X 28.

JG808 Melanephelinite resembling melteigite, Kerimasi. Ord. light. X 28 Indicates the breakdown of aegirine-augite by veins of nepheline.

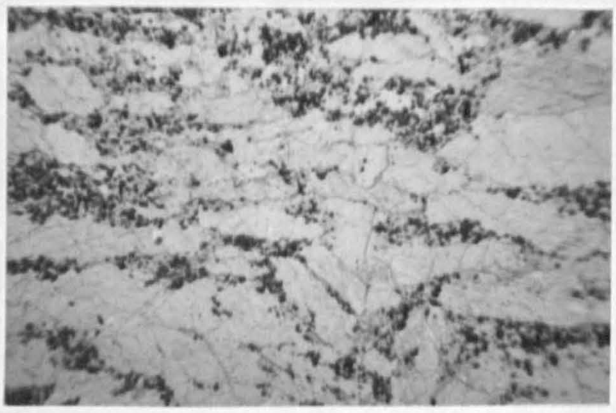


JG810(2) Magnetite-rich carbonatite, Kerimasi. Ord. light. X 28.

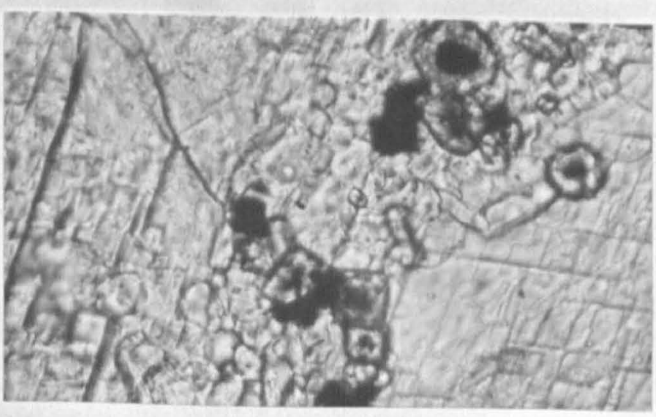
JG813 Melanephelinite resembling melteigite, Kerimasi. Ord. light. X 28. Shows corona of dark biotite around diopside.



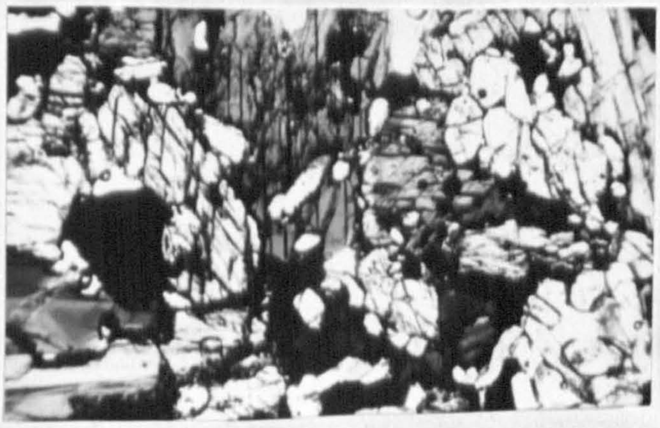
JG814(2) Melanite-biotite-ijolite, Kerimasi. Ord. light. X 88. Very small but abundant melanites associated with magnetite in nepheline.



JG814(3) Carbonatite, Kerimasi. Ord. light. X 28. The dark veins contain magnetite, forsterite, and spinel.



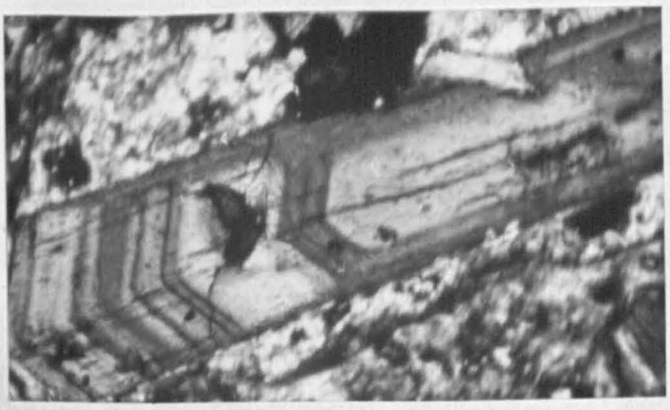
JG814(3) Carbonatite, Kerimasi. Ord.light. X 396. Showing spinels with a magnetite core and sometimes perimeter of magneite with apatite and forsterite, in calcite.



JG818 Pyroxene-amphibolite from Kisetey. Ord. light. X 28.

JG828 Carbonatite, Kerimasi. Ord. light. X 88. Apatite and ore in calcite.

JG838 Nephelinitic-phonolite with feldspar phenocrysts. Oldonyo L'Engai. Polar. light X 28.

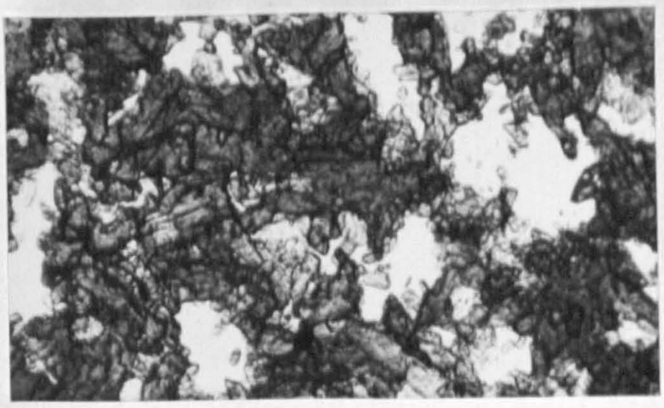


JG853 Calcareous tuff, Kerimasi. Polar. light. X 88. Shows zoning in aegirine-augite crystal.

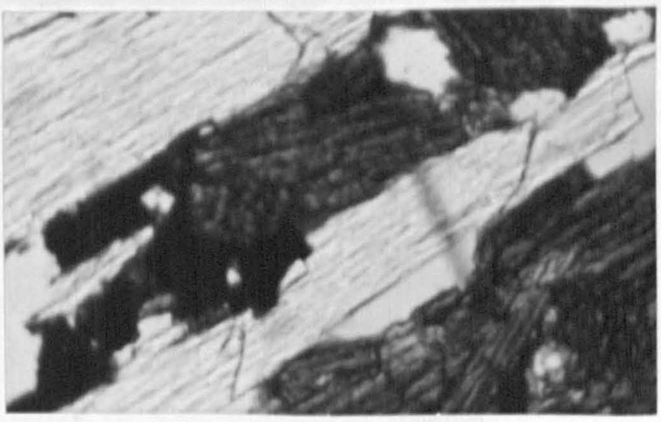
JG865(1) Melanephelinite resembling melteigite, Oldonyo L'Engai. Ord. light. X 28. Biotite bearing variety.

JG866 Nephelinitic-phonolite with feldspar phenocrysts. Oldonyo L'Engai. Polar. light. X 28.

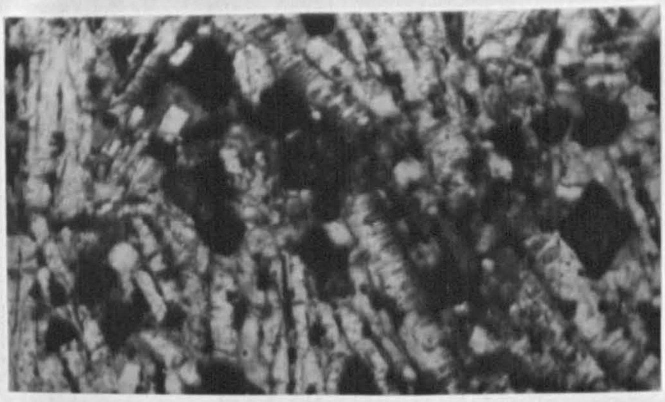
JG868(1) Fenite, Oldonyo L'Engai. Polar. light. X 88. Showing orthoclase crystals in various forms, and some isotropic aegirine-augite at 11 o'clock.



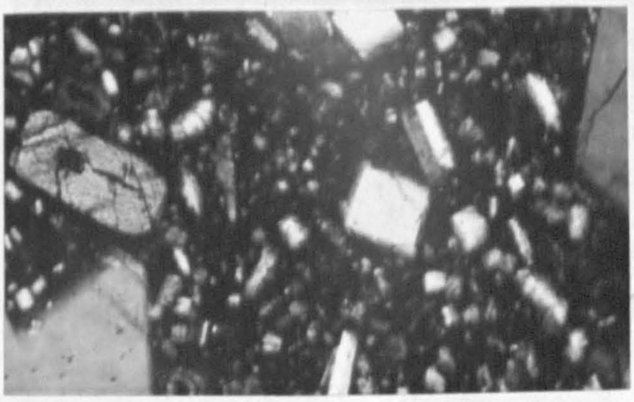
JG870(2) Tveitasite, Oldonyo L'Engai. Ord. light. X 88. Aegirine-augite and orthoclase.



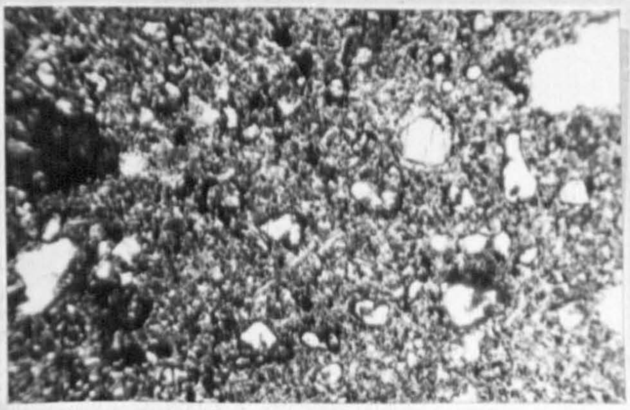
JG875 Wollastonite-melteigite, Oldonyo L'Engai. Ord. light. X 88. Shows some interstitial melanite and apatite, besides the wollastonite and aegirine-augite.



JG888 Melilite-basalt, Oldonyo L'Engai. Ord. light. X 88. Besides the melilite, magnetite and perovskite are abundant, and olivine is present.

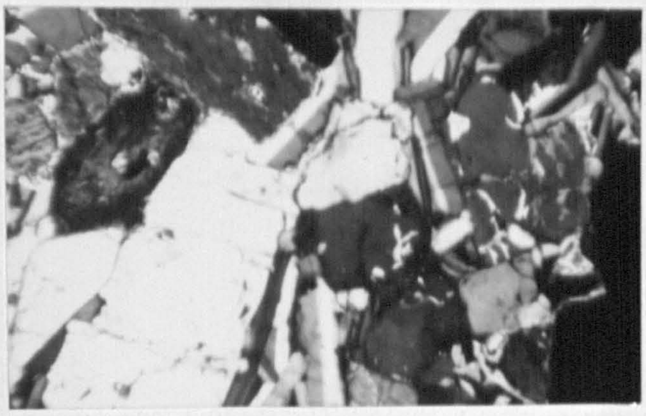


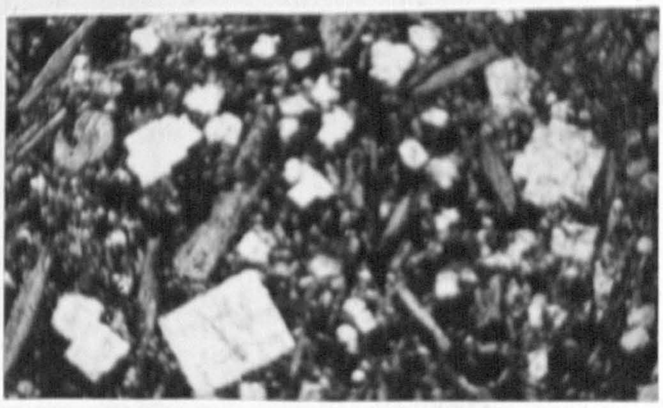
JG892 Nephelinitic-phonolite with feldspar phenocrysts, Oldonyo L'Engai. Polar. light. X 88.



JG899 Nepheline-melabasalt, Gelai. Ord. light. X 28. Showing the large quantity of olivines with iddingsite border, and part of an olivine phenocryst.

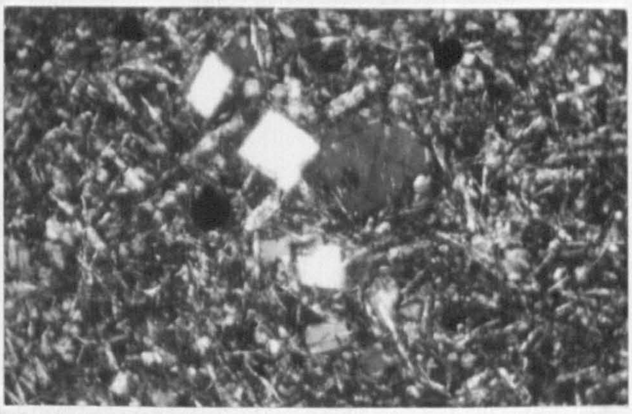
JG917 Phonolitic-trachyte, Gelai. Polar. light. X 28. To show the crossed hatched twinning of the anorthoclase.

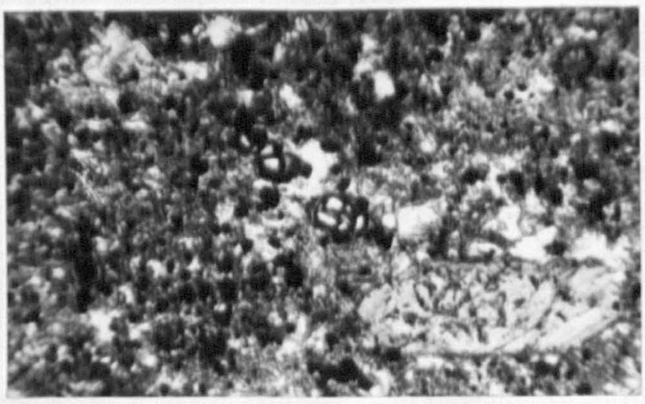




JG965(3) Nephelinitic-phonolite with feldspar phenocrysts. Mosonik. Polar. light. X 79.

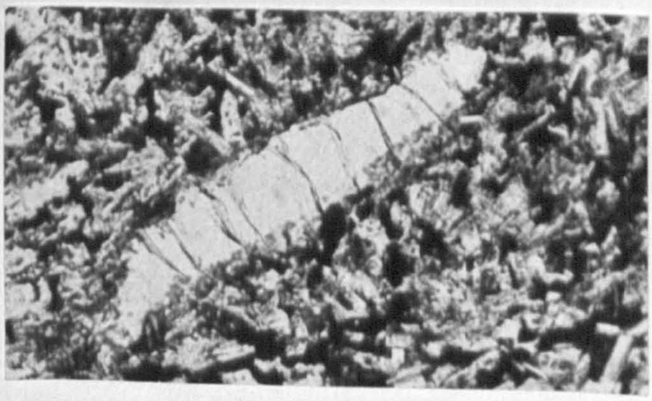
JG968 Melanephelinite, Mosonik. Ord. light. X 28.

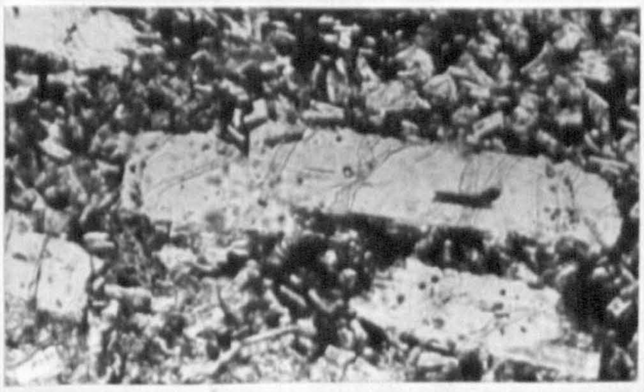




JG969(1) Melanephelinite, Mosonik, Polar. light. X 88. Euhedral nepheline, needles of aegirine-augite, ore and some sphene.

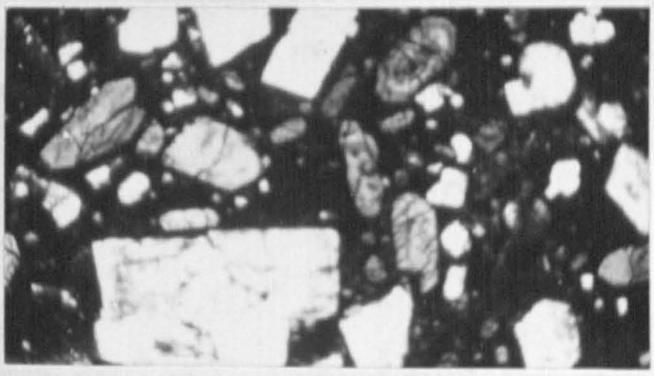
JG977 Nepheline-andesite, Rift wall, Oldonyo Sambu area. Ord. light. X 28. Very rich in olivines, often with iddingsite border.



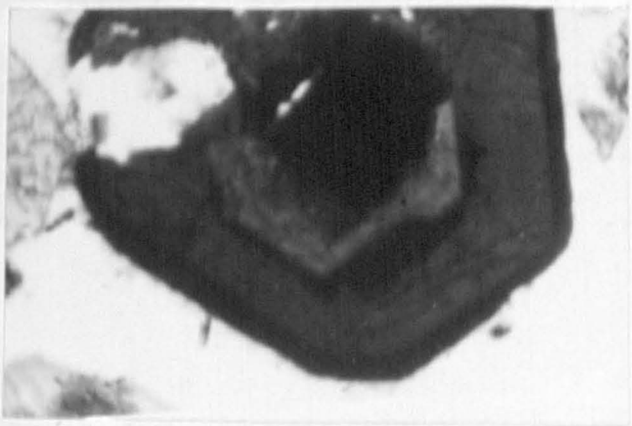


JG1142 Riebeckite-trachyte, Kibangaini. Ord. light. X 88. Note the typical cracks on the large orthoclase crystal.

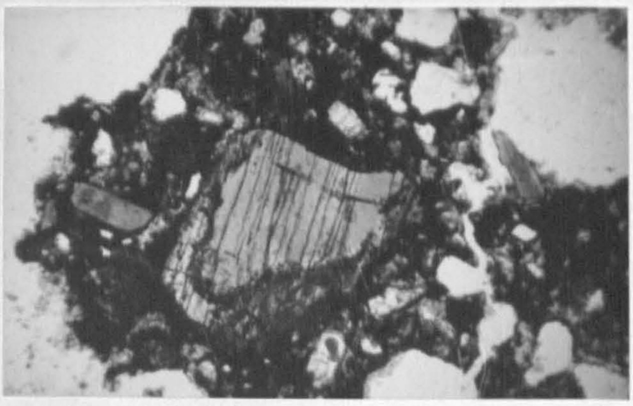
JG1145 Trachyte, Kibangaini. Ord. light. X 88. The darker material is riebeckite, aegirine-augite and barkevikite.



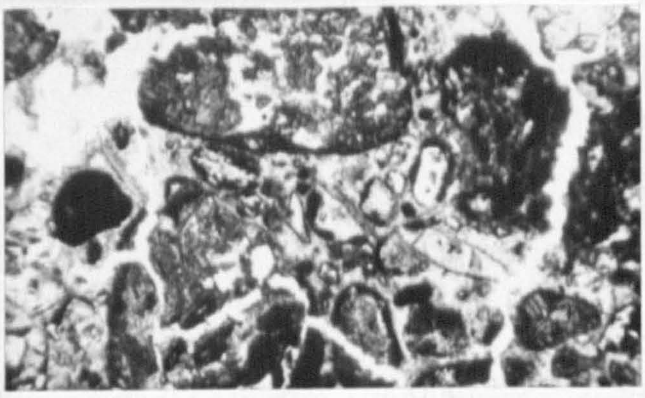
JG1163 Melanephelinite, Shombole. Ord. light. X 28.



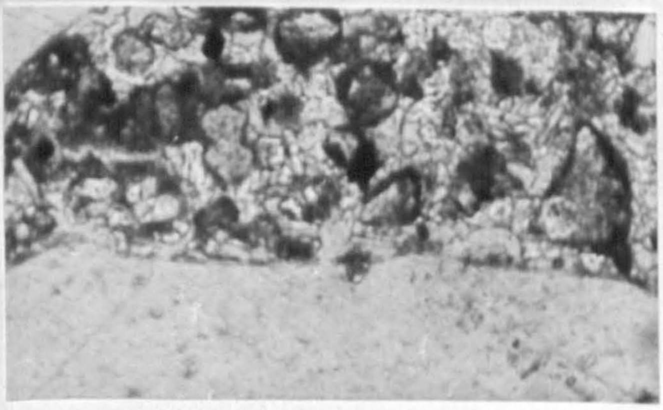
JG1251 Calcareous-tuff, Kerimasi. Ord. X 88. Zoning in melanite.



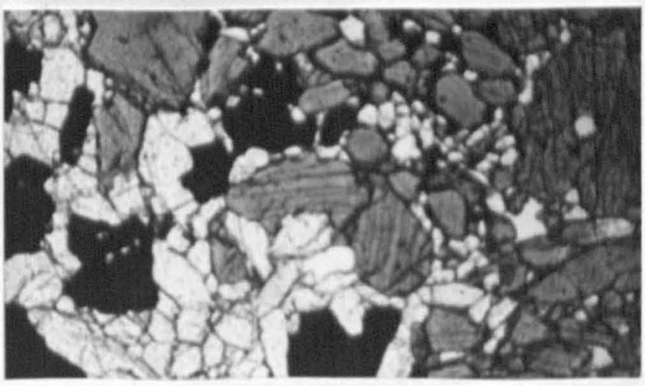
JG1256 Calcareous tuff, Kerimasi. Ord. light. X 28. Note the border of inclusions in the aegirine-augite fragment.



JG1262(2) Calcareous tuff, Kerimasi. Ord. light. X 28. Rock and crystal fragments in a ferruginous and calcitic cement.



JG1266 Carbonatite, Kerimasi. Ord. light X 88. Vein carrying small garnets, ferruginous matter and apatite, in the calcite.



JG1274(3) Melanephelinite resembling melteigite. Oldonyo L'Engai. Ord. light. X 28. Rich in apatite.

THE GEOLOGICAL STRUCTURE OF THE OLDONYO L'ENGAI AREA OF TANGANYIKA TERRITORY.

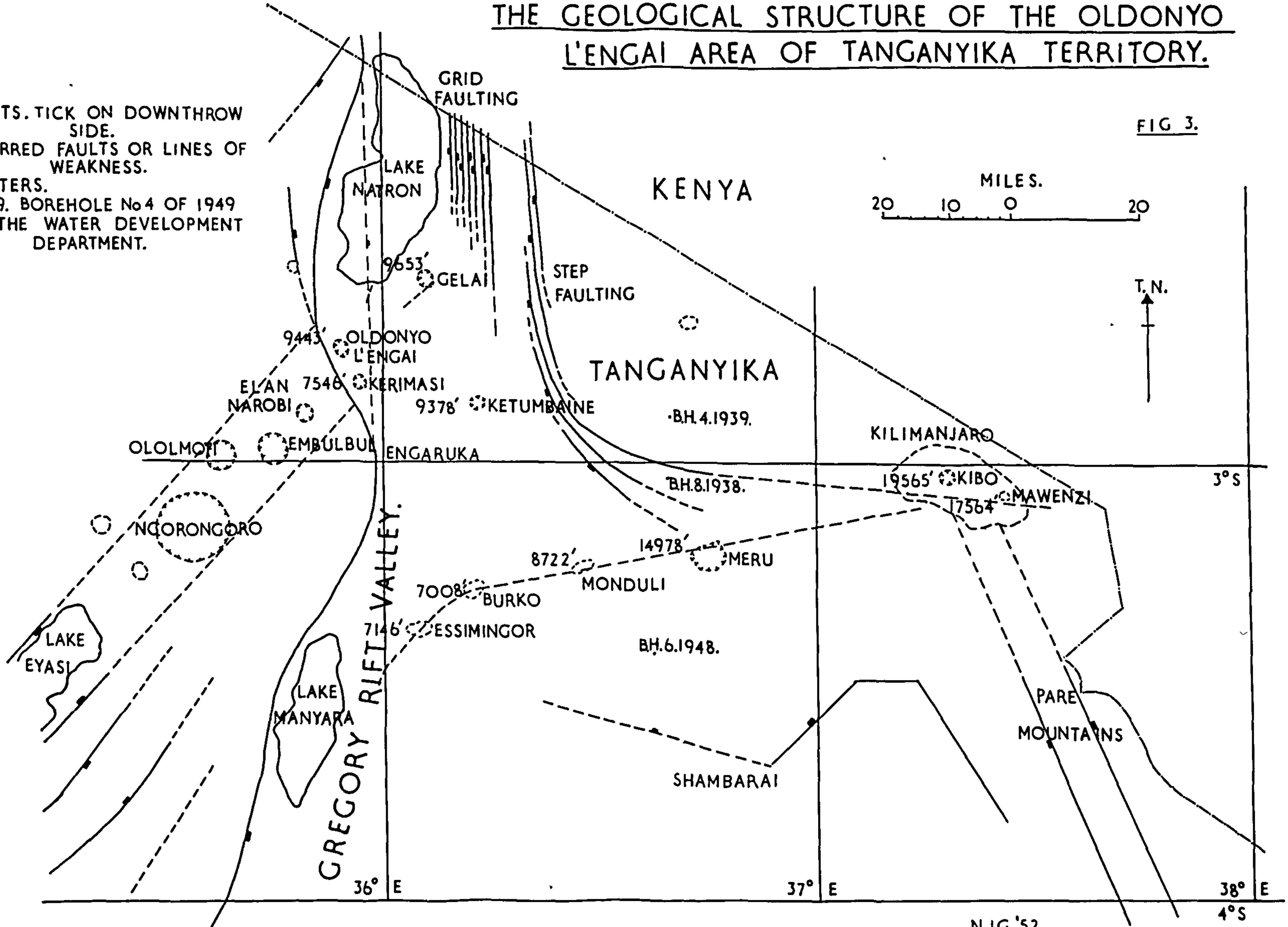


FIG 3.

FIG. 11. VARIATION DIAGRAM KERIMASI.

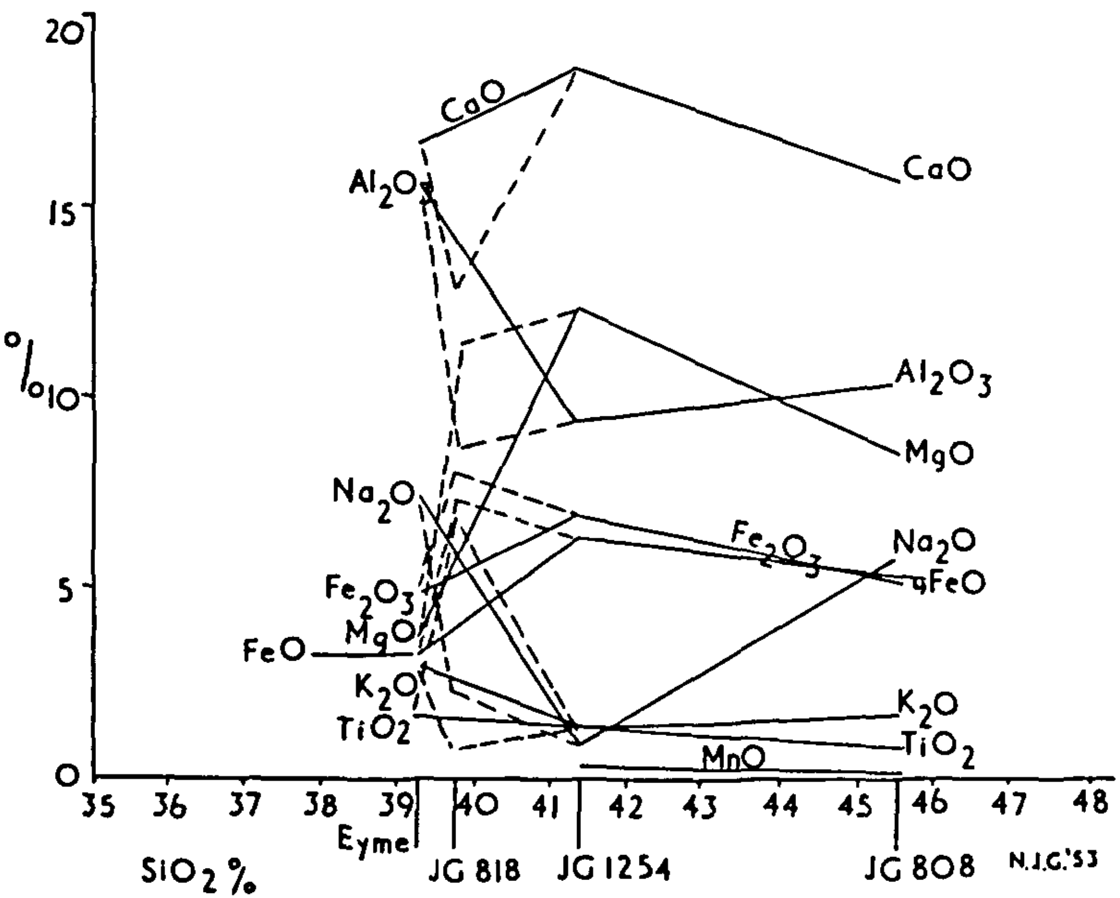
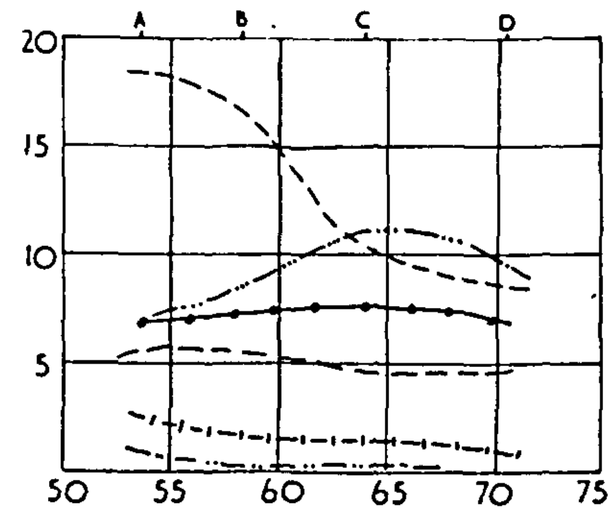


Fig 10. VARIATION DIAGRAM AFTER HARKER



A Kenyte Mount Kenya
B Phonolite Mount Kenya
C Phonolitic obsidian L. Nakuru
D Soda-rhyolite L. Naivasha

N.J.G '53

FIG. 7 SECTION ACROSS THE MORE RECENT DEPOSITS OF LAKE NATRON.

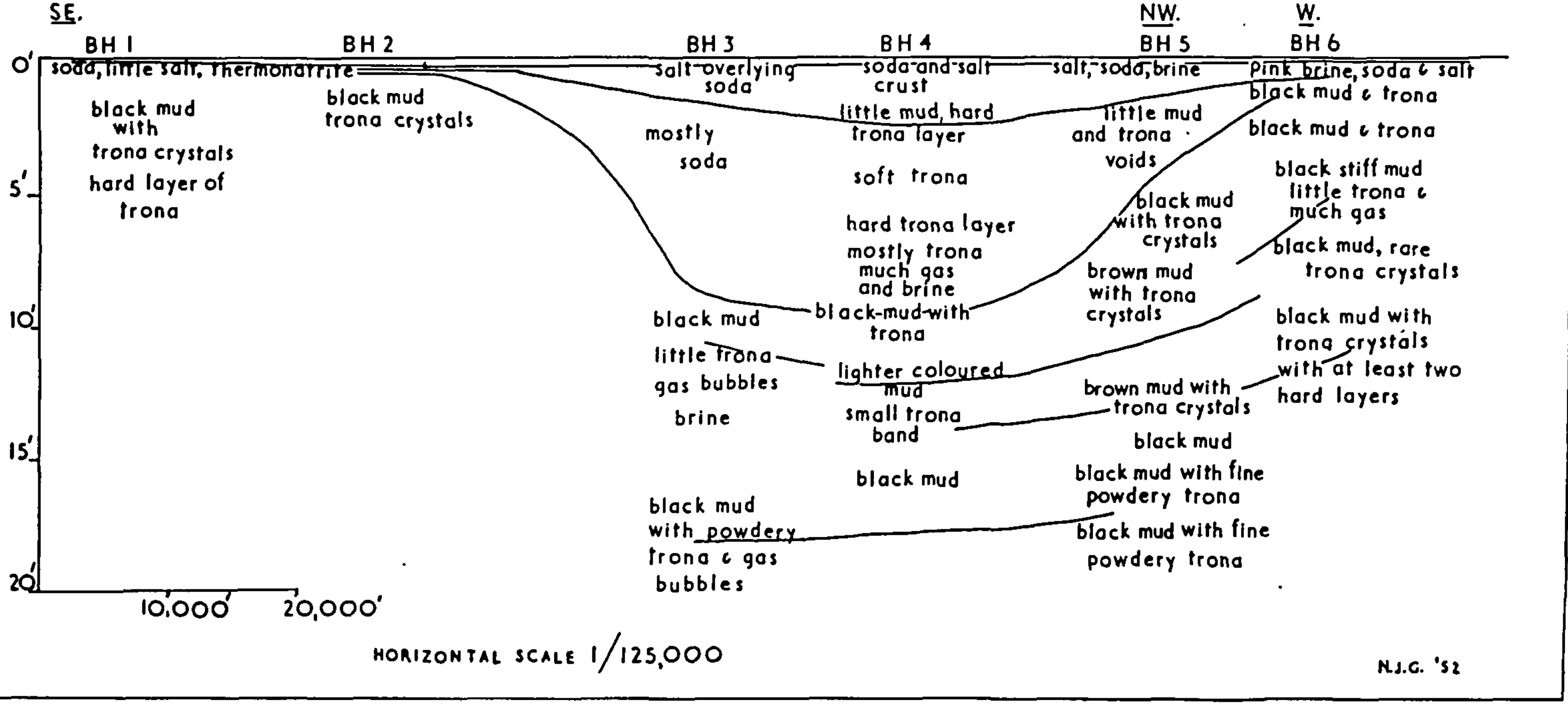


FIG. 9. VARIATION DIAGRAM 1. OLDONYO L'ENGAI. 2. GELAI AND KIBANGAINI.

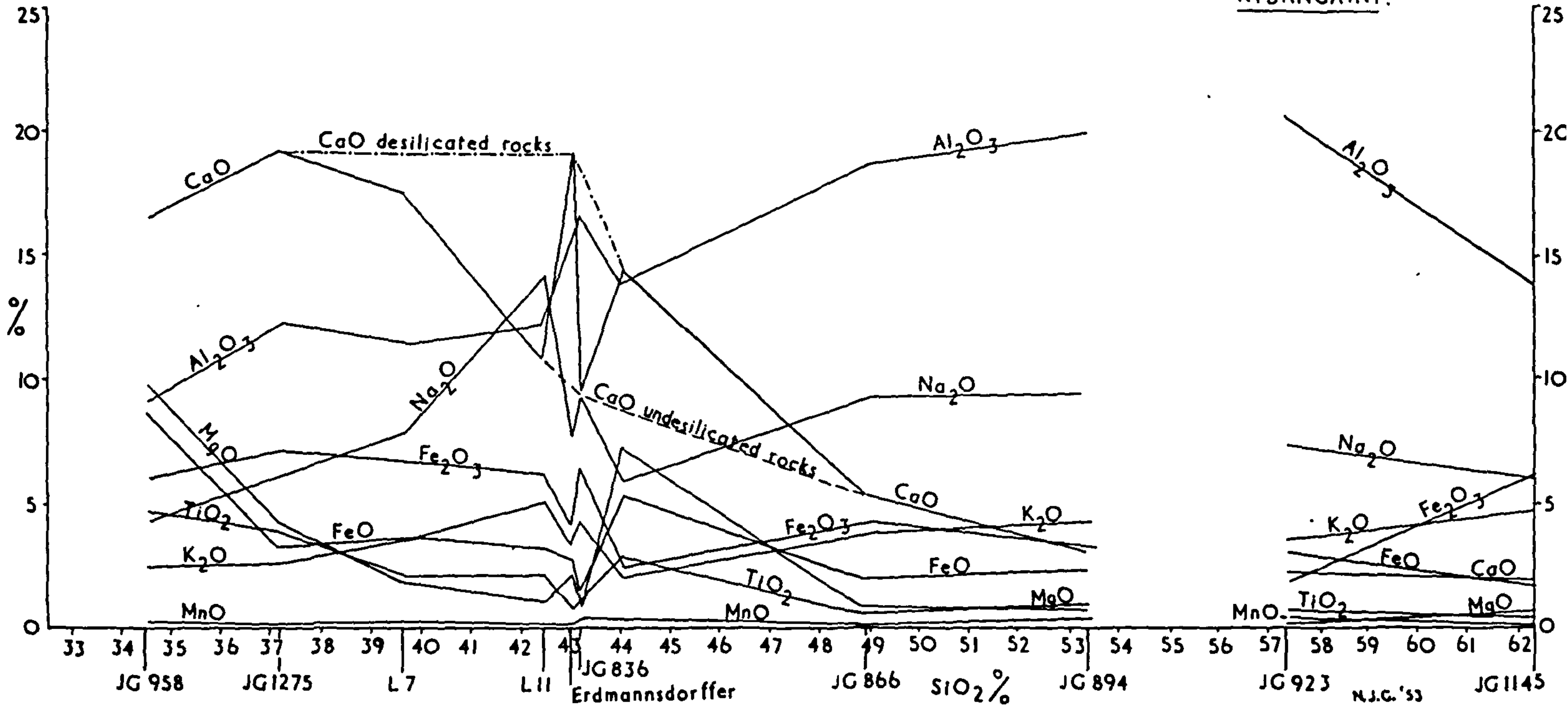
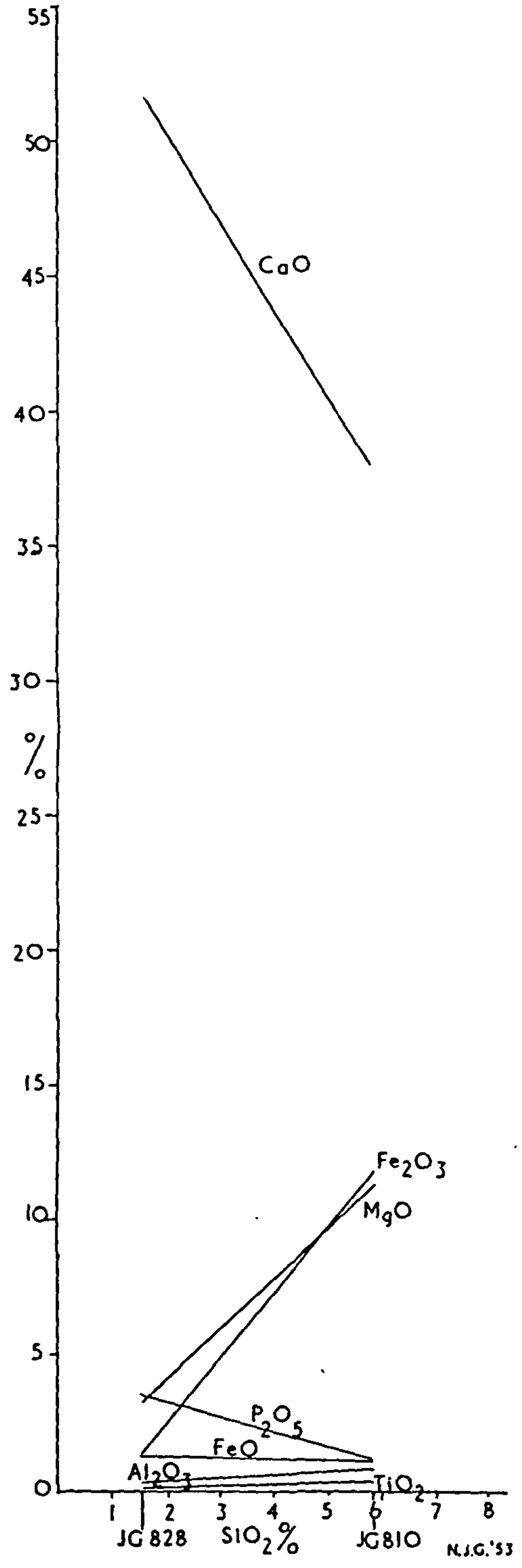
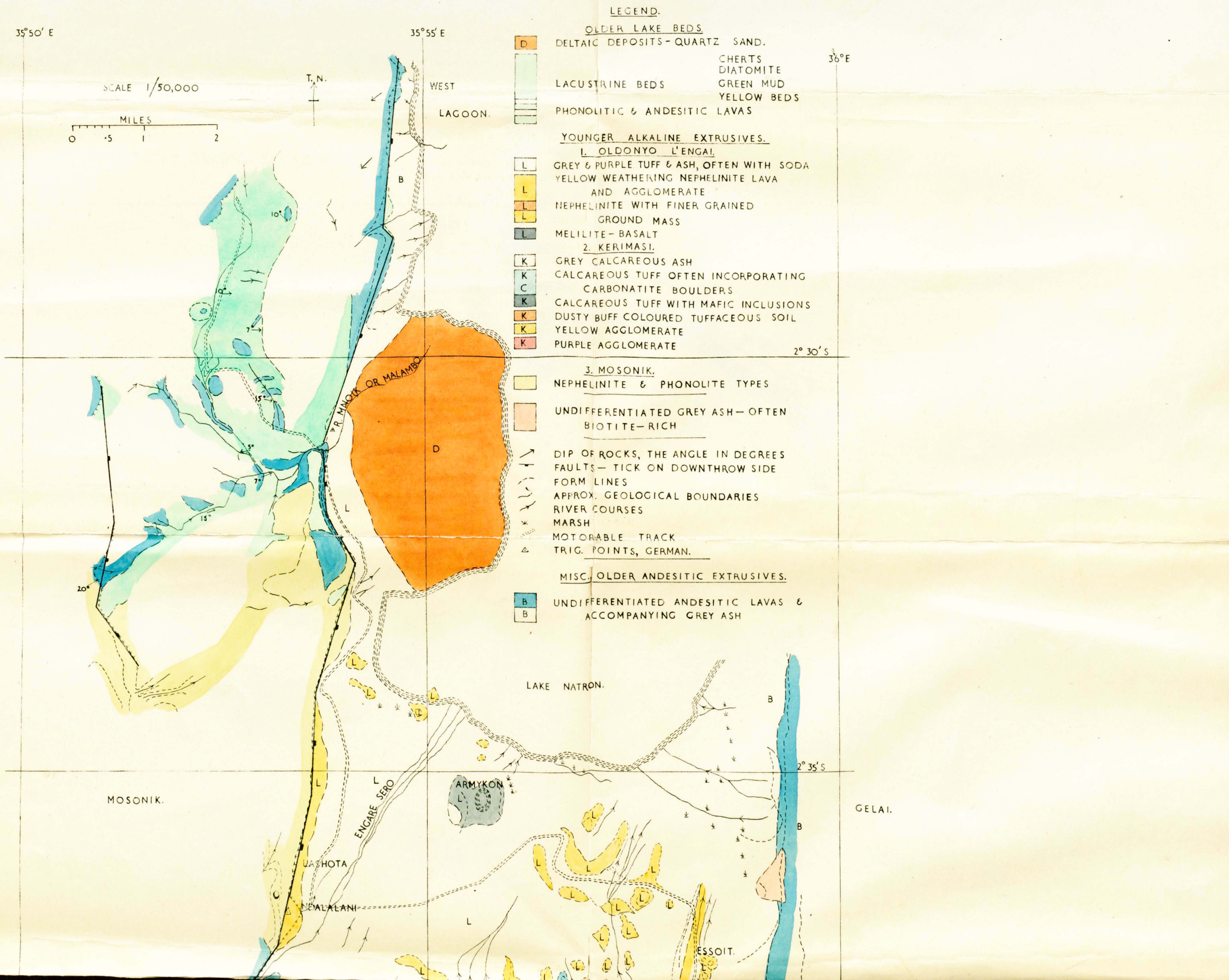


FIG. 12. VARIATION DIAGRAM
KERIMASI CARBONATITES.

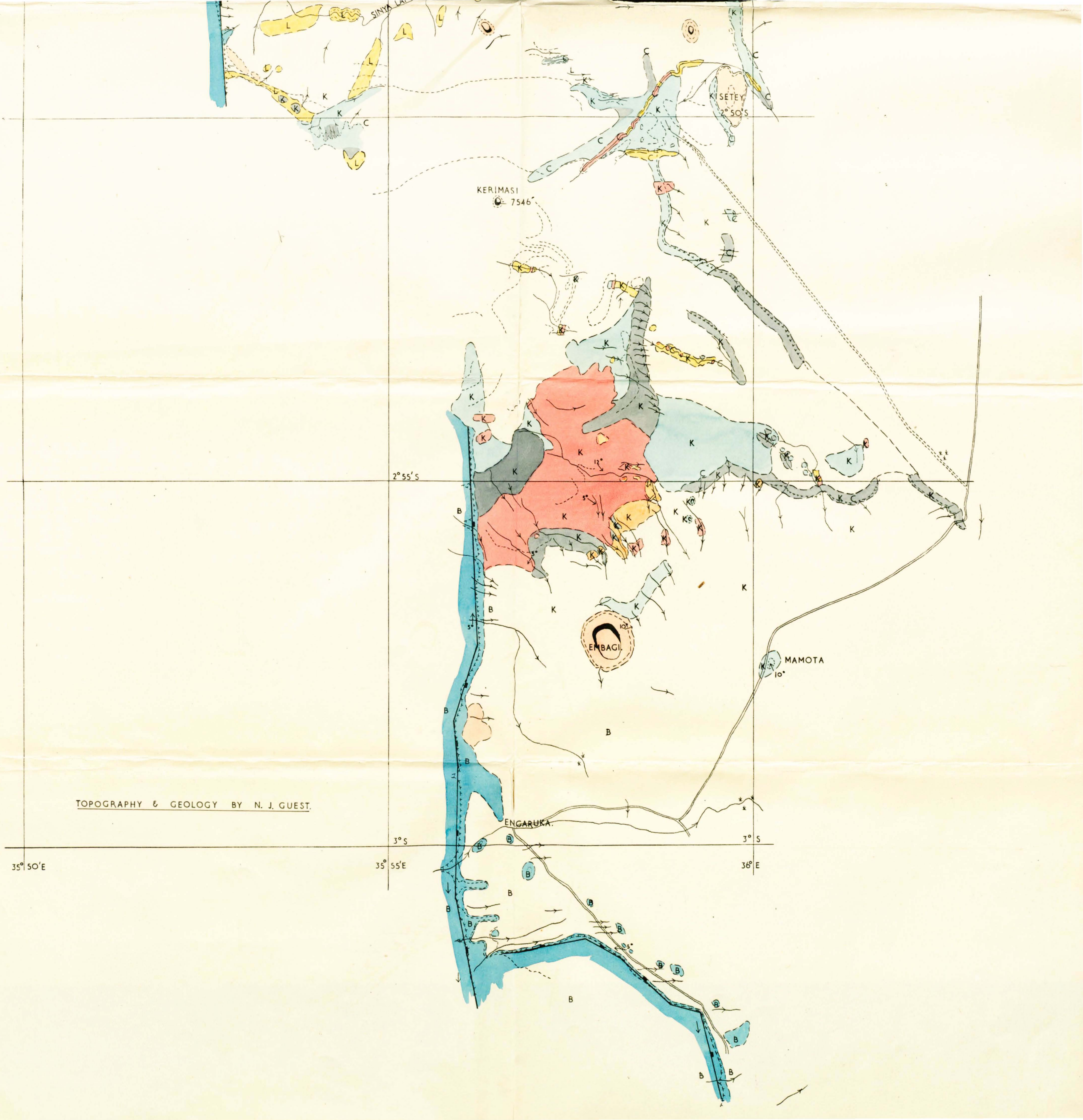


GEOLOGICAL MAP OF THE OLDONYO L'ENGAI AREA IN THE GREGORY RIFT VALLEY OF TANGANYIKA TERRITORY.

FIG. I.



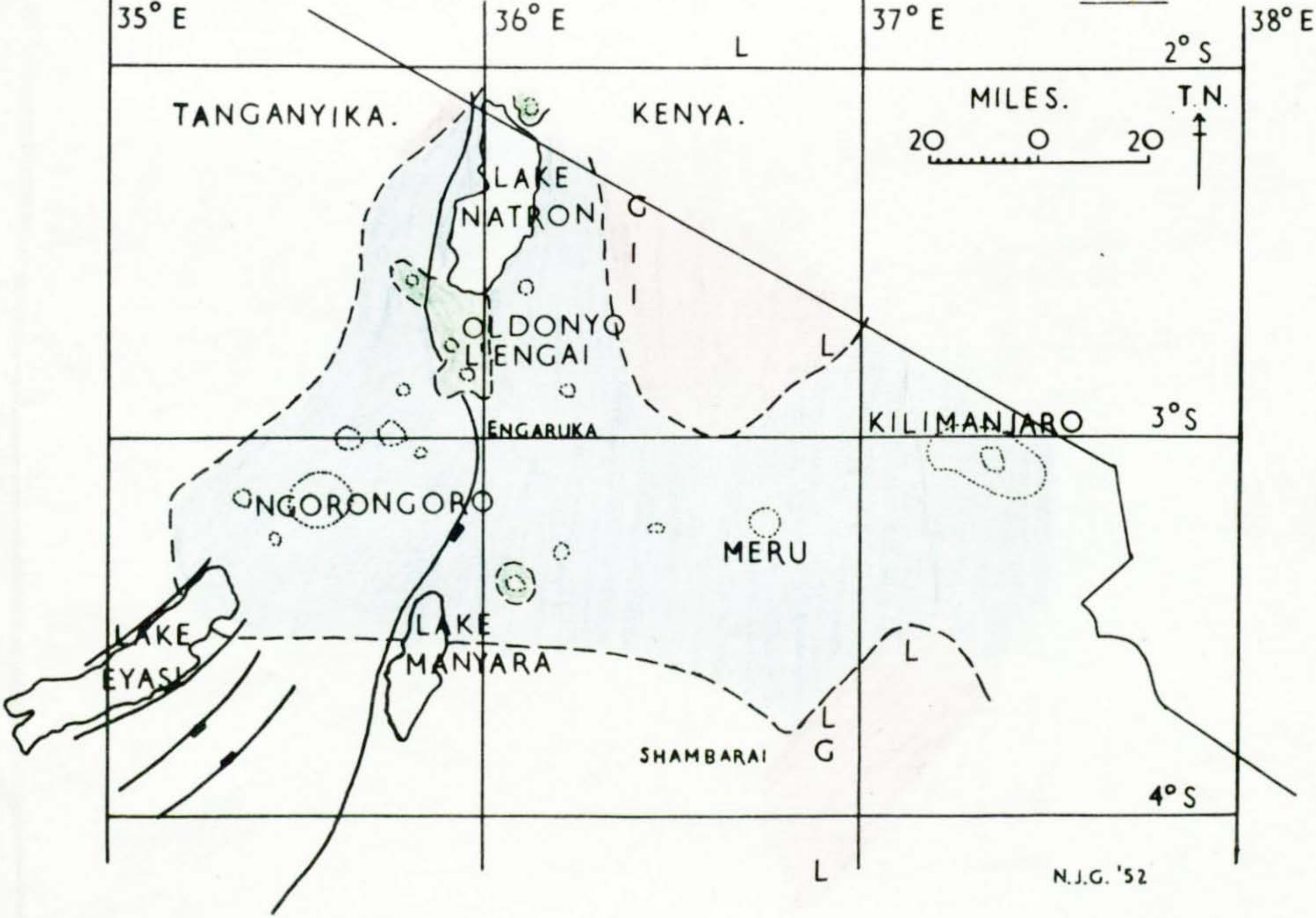

TRIG. POINTS, GERMAN.
MISC. OLDER ANDESITIC EXTRUSIVES.
UNDIFFERENTIATED ANDESITIC LAVAS & ACCOMPANYING GREY ASH
LAKE NATRON.
2° 35' S
MOSONIK.
ARMYKON
ENGARE SERO
GELAI.
ESSOIT.
GELAI.
2° 40' S
OLORGOGORIE.
OLDONYO L'ENGAI 9443'
LALARASI.
2° 45' S


SINYA
KERIMASI
7546'
KISETEY
2° 50' S
2° 55' S
EMBAGI
MAMOTA
ENGARUKA
3° S
3° S
35° 50' E
35° 55' E
36° E
TOPOGRAPHY & GEOLOGY BY N. J. GUEST.

SKETCH MAP INDICATING THE GEOLOGY OF THE OLDONYO L'ENGAI

AREA – TANGANYIKA TERRITORY.

FIG. 2



ALKALINE TYPES. TERTIARY TO RECENT
BASALTIC TYPES. EXTRUSIVES.

BASEMENT COMPLEX.

G GRAPHITE SCHIST.

DOLOMITIC CRYSTALLINE LIMESTONE –

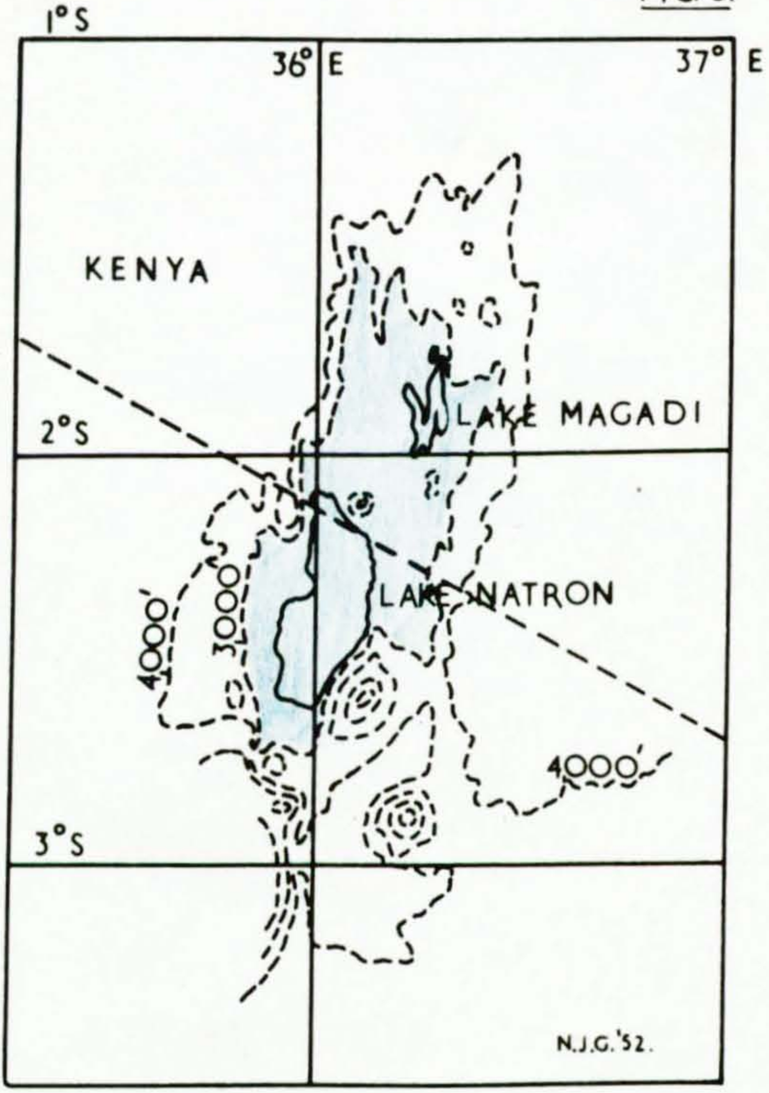
L LARGE OUTCROPS.

I SMALL OUTCROPS.

RIFT FAULTING TICK ON DOWNTHROW SIDE.

THE INLAND DRAINAGE AREA OF THE MAGADI & NATRON LAKES

FIG. 6.



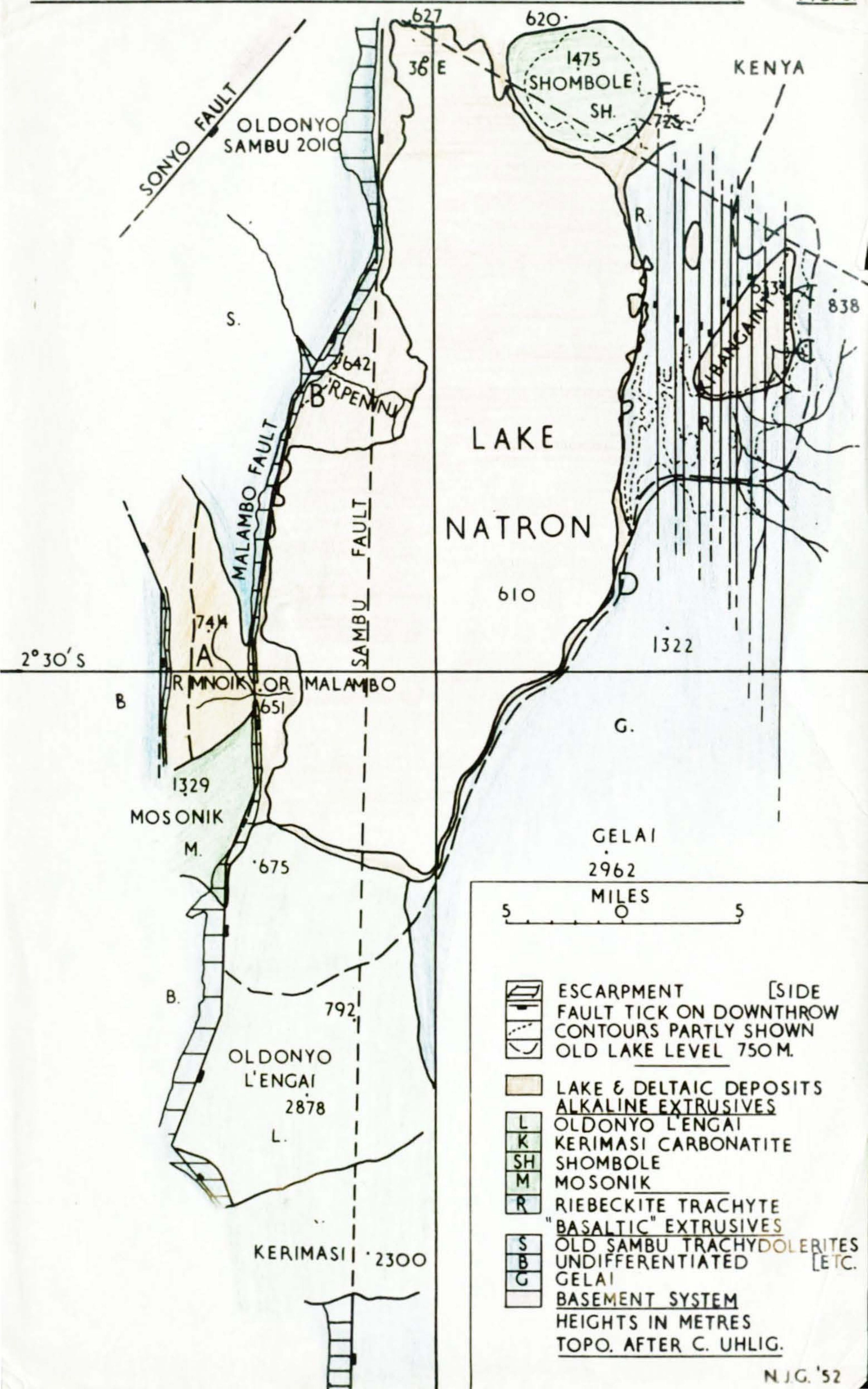
MILES

20 0 20

AREA BELOW 3,000' — POSSIBLE SHORELINE OF THE UNITED LAKES MAGADI AND NATRON

THE GEOLOGY OF THE LAKE NATRON AREA.

FIG. 5.

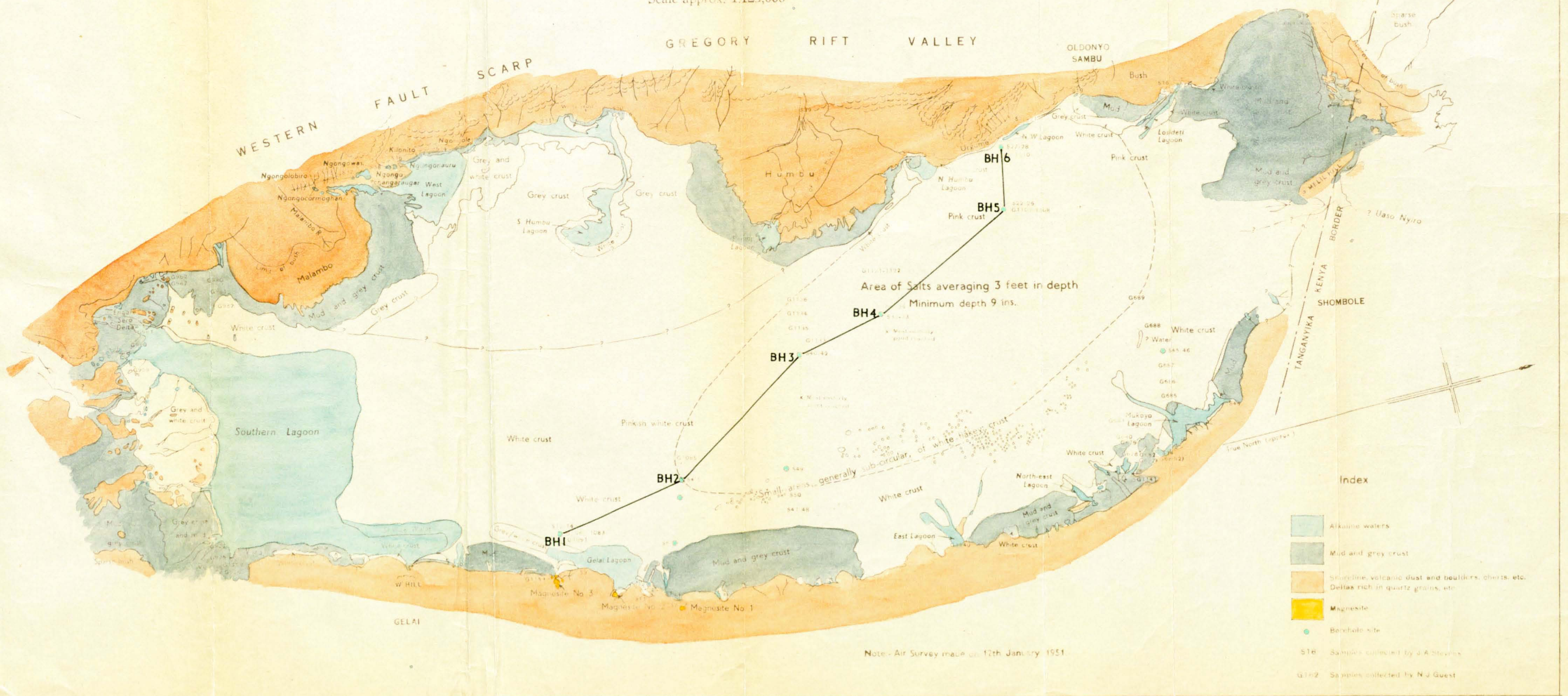


LAKE NATRON

FIG. 4.

Compiled by N.J.Guest and J.A.Stevens from Air Photographs taken by the Civil Aviation Division, Dept of Surveys and Town Planning and the 1:150,000 map 'Die Ostafrikanische Bruchstufe' by Carl Uhlig, 1904.

Scale approx. 1:125,000



M.R.P.58

Geological Survey Dept., Dodoma 1951.

LOCALITIES OF CARBONATITE COMPLEXES IN EAST AND CENTRAL AFRICA.

FIG. 8.