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MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES
MINES AND GEOLOGICAL DEPARTMENT

GEOLOGY

OF THE

SULTAN HAMUD AREA

(with colored geological map)

EXPLANATION OF DEGREE SHEET 59, N.W.

by

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Geologist

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FOREWORD

The Sultan Hamud area, which is less than 100 miles south-east of Nairobi, has attracted public attention several times in recent years owing to proposals to manufacture cement there. Some years ago a well-known Kenya prospector discovered a few miles south of Sultan Hamud Station outcrops of crystalline limestones that were found on analysis to be unusually poor in magnesia. Limestones containing little magnesia are essential for the manufacture of British Standard Portland cements, and the discovery at Sultan Hamud was of considerable importance. Not only is the geographical situation satisfactory, but the occurrence of magnesia-poor limestones in the Basement System—of which the Sultan Hamud limestones form part—is unusual. There are enormous reserves of limestone available in Kenya in the bands of Basement System marbles that are found at numerous localities in the central meridional zone of the country. Most of them, however, prove on analysis to contain considerable proportions of magnesia and, indeed, are sometimes almost true dolomites, so that they are unsuitable for use in cement manufacture.

It is disappointing that so much time has elapsed since the discovery of the limestones before any concrete evidence of their use has appeared. A company was formed to exploit the deposits in 1949 and the Geological Survey gave considerable assistance in the mapping and investigation of the limestones, and a brief account of some of the results obtained is given by Mr. Searle in the report. The company failed in 1951, and it was not until early in 1953 that once again practical consideration was given to the Sultan Hamud limestones. It is hoped that the present commercial investigation that is being carried out will lead eventually to the production of cement.

A few other economic minerals have been found in the area—notably mica, beryl and kyanite. During the last war small amounts of good quality mica were extracted from pegmatites, but interest has since waned. Beryl and kyanite have not been commercially extracted, and it is unlikely that beryl would be, except as a by-product in the mining of mica. During his survey Mr. Searle discovered deposits of kyanite schists that gave good promise of being extensive and suitably rich for the extraction of kyanite. Subsequent more detailed examination showed that the dilution of the deposit by non-kyaniteiferous rock was much greater than had at first been thought, and that the overall average kyanite content was much lower than originally estimated. The presence of kyanite-bearing rocks in the area, however, is now well substantiated, and a more detailed search may well reveal deposits of economic size and tenor.

Geologically the northern part of the area reflects the unusual concentric structures already described by Mr. B. H. Baker in Report No. 27 on the southern Machakos area. Mr. Searle graphically likens them to whirlpools in a fast-flowing stream, but the mechanism of their formation appears to be that of the slow rotation of solid rocks around centres that had been softened by heat and metasomatic solutions. The centres are of considerable importance as they are closely connected with the origin of nearby pegmatites, in which the mica and beryl are found, and which also in some cases contain minerals of the columbite group. Suggestions have been made that the concentric structures may have arisen as a result of vertically upward pressures and may be connected with carbonatite intrusions. Mapping in the Sultan Hamud and Machakos areas, however, lends little support to such ideas. There are numerous limestones, but no suggestion that they are carbonatites, while structural evidence indicates that pressures were tangential.

Nairobi,
25th April, 1953.

WILLIAM PULFREY,
Chief Geologist.

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MAP

Geological map of the Sultan Hamud area (degree sheet 59, N.W. quadrant), Scale 1:125,000
At end

ABSTRACT

The report describes an area in the Masai Native Reserve of southern Kenya enclosed by latitudes 2° S. and $2^{\circ} 30'$ S. and by longitudes 37° E. and $37^{\circ} 30'$ E. Three morphological features are recognized: (1) the relics of the end-Cretaceous peneplain; (2) the end-Tertiary peneplain, and (3) the volcanic region south of Emali.

Basement System rocks of the area comprise a metamorphic series of pelitic, psammitic and calcareous rocks which have been intensively metasomatized by alkaline fluids. Marbles have remained free from granitization and their economic significance is discussed together with that of mica and kyanite. Quaternary rocks are represented by a series of lavas and pyroclastic rocks which form the western prolongation of the Chyulu Hills. Olivine-basalt flows heralded the outburst of a vast amount of agglomerate, breccia and ash which built up steep-sided cinder cones around each vent. The petrography of the various rock types is described and the progressive effects of granitization upon the Basement System rocks are considered. An account of major and minor structures is given, and the origin of a peculiar circular structure in the neighbourhood of Sultan Hamud is tentatively ascribed to rotation under tangential stress.

GEOLOGY OF THE SULTAN HAMUD AREA

I—INTRODUCTION

The area covered in this report comprises the north-western quadrant of degree sheet 59 (Kenya Colony), roughly 1,225 square miles in extent, bounded by latitudes 2° S. and $2^{\circ} 30'$ S., and by longitudes 37° E. and $37^{\circ} 30'$ E. The greater part of the area lies in the Masai district but a small portion of the Kamba Native Reserve and some Crown land is also included.

Environment.—Sultan Hamud is 74 miles from Nairobi. To the north lies the intensively cultivated land of the Kamba tribe, whilst to the south stretches a vast expanse of grassland over which roam the Masai and their herds of cattle. The flat area enclosed by the Emali-Mashuru road is predominantly grass covered, with widely dispersed acacia trees. Shrubs increase in density on the hills south of Sultan Hamud, the valleys running up to the summit of Emali Hill being thickly wooded. Southward from the Mashuru-Emali road the country is gently undulating in which thick scrub alternates with open grassland. Areas either predominantly grassland or scrubland are indicated on the map. The portion of the area south of the railway is a Game Reserve, whilst between Elemborasha and Leme Boti, lies the northern boundary of the Amboseli National Reserve. Buffalo haunt the wooded slopes on the Emali Hills whilst rhinoceros, elephant, lion, leopard, giraffe and vast numbers of many types of buck are commonly observed throughout the area. Herds of elephant can be seen in the wet season along the banks of the Selengai River as far north as Mashuru.

No perennial river flows through the area. The Masai formerly obtained their water entirely from water-holes or from small wells dug in the sand-rivers, though in exceptionally long, dry seasons most of the water-holes would become dry, causing severe loss of cattle. The Masai even nowadays employ outside African labour to dig wells for them in the beds of sand-rivers in the dry season in order that they may water their cattle. These wells are, of course, only temporary. In recent years the Local Native Council has approved the spending of large sums of money for the drilling of wells and for the installation of pumping machinery and other equipment. Water storage tanks are built of concrete and are surrounded at the base by a narrow trough from which cattle may drink. The pumps are operated by outside labour, usually Wakamba, under the direction of the local Public Works Department, and come into operation only in the dry season. It is important that such bore-holes should be as widely distributed as possible to prevent congestion, overgrazing and domestic problems.

Most of the area, especially in the south, becomes waterlogged in the wet season and movement by truck is impossible. The headwaters of the Selengai drain a large area and in a matter of a few minutes a small trickle of water can suddenly become a brown, muddy, roaring torrent, 12 ft. deep, sweeping away all obstacles that lie in its path.

Emali and Sultan Hamud are small trading centres on the Nairobi-Mombasa Railway from which one may purchase provisions and petrol. Mashuru is a Masai trading centre where there is a dispensary with a Masai dresser, and a school. There is also a shop for local trade only at Selengai. A private dispensary is run by Mrs. P. H. Cull a few miles to the south of Sultan Hamud.

Communications.—The area is accessible from Namanga, Kiu, Kajiado and Emali. Apart from the main Nairobi-Mombasa highway, which passes through Sultan Hamud and Emali, all other roads become impassable after short periods of rain. Being in a little frequented area such roads receive scant attention and in the wet season are washed away or become channels for flood water; culverts become blocked with alluvium or are washed away, and remain in that state for several months.

Rainfall.—Annual rainfall figures show that in general the precipitation decreases from north to south. At the Roman Catholic Mission at Mbitini the average precipitation over a period of seven years is 39.5 in.; at the Kazikeo (Kasikiu) school, Sultan Hamud, the average over ten years is 30 in., and at Mashuru, over a period of five years, 22.4 in. Heavy rainfall during 1951 will no doubt increase these averages by several inches.

Maps.—Sultan Hamud and Emali Townships, the Native Land Unit boundaries and farm boundaries were plotted from the Cadastral Map $\frac{\text{South A-37}}{\text{N I b}}$. Minor survey points were plotted with a plane-table and compass with telescopic sight, whilst river-courses, form-lines and other topographical details were plotted direct from aerial photographs. The flight runs and principal points of these photographs are shown on the map.

PREVIOUS GEOLOGICAL WORK AND HISTORY OF THE AREA

Joseph Thompson (Loftus, 1951)* was one of the earliest explorers to pass through the area, travelling in 1883 from the eastern side of Mt. Kilimanjaro, by Lake Amboseli, to Ol Donyo Orok. Very few people have traversed the area between Lake Amboseli and the Selengai River and the most recent maps of the district refer to it as the Nyiri Desert. The word "desert" in its popular sense is misleading since there is natural vegetation of grass and thorn scrub.

Mica prospecting was undertaken in the area many years before the Second World War but it was not until 1939-40 that much mica was produced from the hills to the south of Sultan Hamud. P. H. Cull, who has spent many years prospecting in the area, discovered numerous occurrences of crystalline limestone suitable for cement manufacture. Dr. Temperley spent several weeks mapping the major outcrops in 1949 and his findings and recommendations are embodied in unpublished departmental reports. It was in view of the possible economic importance of marble, mica, beryl and asbestos that a geological reconnaissance survey was undertaken between November, 1950, and July, 1951. J. W. Gregory (1921, p. 189-191 and 144-5) makes the only published geological reference to the area. He mentions that olivine-basalt flows derived from the two craters Kelembwani and Mwani, occupied the original valley floor of the Kiu River causing it to be divided into two streams, the Kwawatingila and the Kiu. He also states that the lava passed over an old land surface and that at the junction between the lava and the underlying gneiss a water-bearing horizon should exist. This deduction has since proved correct.

II—PHYSIOGRAPHY

The area can be divided into two physiographic regions, the hills around Sultan Hamud and the flat plain extending south to Lake Amboseli.

One of the highest points of the area is Emali trigonometrical beacon which attains a height of 5,953 ft. and there seems little doubt that the Emali hills are remnants of the so-called end-Cretaceous peneplain (cf. Shackleton, 1946, p. 44) which lies at an altitude of 6,400 ft. in the Machakos District. Lolondo, Kabaini and Musuriamboi, lying at or slightly above 5,000 ft., are remnants of the younger sub-Miocene peneplain,

* References are quoted on p. 36.

upon which, to the north of the area, lies the Kapiti phonolite. The remainder of the area below 5,000 ft. is regarded as part of the end-Tertiary peneplain, which is well-developed and slopes to the south-east. It grades imperceptibly in the north-west, where heights average 4,500 ft., into the sub-Miocene peneplain. An abrupt change of level of 200 ft. occurs to the south-west between Musuriamboi and Tolokeraï and is due to erosion by the Bissel River. A flat area lying at 4,000 ft. between Emali and Masui forms part of an old river terrace, most probably associated with the Mkuyu. It is thickly covered by a red sandy soil into which the heads of the streams on the end-Tertiary peneplain have cut their courses.

Strike directions in the Basement System have influenced the direction of flow of the principal rivers. Around Sultan Hamud the river profiles are youthful but reach maturity and old age in the centre of the end-Tertiary peneplain, only to commence a new cycle of erosion as the rivers reach the recent volcanic rocks.

The principal river is the Selengai, which drains a large area south-west of the watershed between Buziani and Kiasa. From its entry into the area from the north to within a few miles of Mashuru it flows through a mature land surface, but south-eastwards from Mashuru the geomorphic cycle attains old age. At approximately five miles west of Olosingoram bore-hole the Selengai River has attained grade and the vast amount of sediment that is carried down-stream from Mashuru in times of flood is deposited there. The river loses its banks and bifurcates into numerous channels which end as suddenly as they begin, the whole width of the aggradation zone extending for over two miles. This area of deposition continues southwards for several miles expanding in width to a maximum of seven miles. The Bissel River likewise divides into braided channels to the west of Tolokeraï and maintains this state for over 12 miles until its confluence with the Selengai. The two rivers meet at a point where their southerly progress diverts eastwards, presumably as a result of Pleistocene vulcanicity, and the combined rivers leave the area in a north-easterly direction to commence a new cycle of erosion.

Early lavas of the Quaternary volcanic episode flowed into other pre-existing channels, but did not cause a great divergence of drainage. The Buziani River for example continues to flow along, or very near to, its original channel. It has been pushed eastwards by the volcanics from Buziani and now follows the junction between the volcanics and the Basement System rocks. From here to the north-west of Kiasa it follows an old-age course, but on reaching the volcanics it is steeply incised into the pyroclastics creating a gorge-like valley, eventually broadening out a few miles before reaching its confluence with the Selengai. Lavas and ash from Ususu have drifted into the Errui River and as a consequence the river may be flowing further to the west than it was previously. The volcanic rocks of the area generally form distinct topographical features imposed upon the normally flat end-Tertiary peneplain.

Drainage southwards from Masui and Mooni is still in a youthful stage but becomes mature before reaching Emali. The drainage in this area is directed to the Mkuyu River and its tributary the Kwawatingila. These are dry sand-rivers but carry vast amounts of water to the Athi during the rainy season.

III—SUMMARY OF THE GEOLOGY

The rocks of the area were formed during two eras, the Archæan and the Quaternary. The former is represented by Basement System gneisses and the latter by a series of volcanic rocks. Many millions of years elapsed between the two eras for which there is no evidence of geological happenings until the end of the Mesozoic era, when a peneplain had developed over an extensive area.

The Basement System consists of a series of metamorphic and metasomatic rocks. The metamorphic rocks are derivatives of a sedimentary series of pelitic, semi-pelitic,

calcareous, carbonaceous and psammitic rocks, in which are found traces of rare basic intrusives. Metamorphic differentiation and segregation, especially among the pelitic and semi-pelitic rocks, have given rise to a series of banded and veined gneisses.

With the notable exception of the marbles, the metamorphic rocks have suffered intense granitization as a result of the introduction of principally soda and potash along various channels and through pores, causing the rocks to develop sufficient plasticity for minor overfolding and intricate fold structures to occur. In this way a second series, of veined gneisses, was formed.

Migmatites are considered to be extremely rare, though some of the granite veins and injection gneisses are thought to have a migmatitic origin. A series of coarse-grained pegmatites has yielded workable deposits of mica.

The Quaternary volcanic era opened with the extrusion of olivine-basalt which flowed into pre-existing valleys. The lava flows were followed by extensive volcanic activity of the explosive type giving rise to thick deposits of agglomerate, breccia and ash around each vent. Very little of the early olivine basalt can be seen to-day as it is covered by later pyroclastics.

Structurally the area contains the most southerly of a series of circular structures found in the Machakos-Sultan Hamud area. Rotational movement caused by east-west compressional forces has produced a "swirl" in the Basement System rocks near Sultan Hamud. The rocks of the south-western part of the area have a general north-west strike with a north-easterly dip. The pitch of lineation is considered to be north-west in the northern portion of this section and south-easterly in the southern portion, but it changes abruptly to north-east and east-north-east in the northern part of the area and around Sultan Hamud.

The area contains economically important deposits of crystalline limestone (marble) which occur close to Sultan Hamud Railway Station. Kyanite and mica are other important minerals, the latter having been worked in the past.

IV—BASEMENT SYSTEM

1. Introduction

The Basement System is represented in this area by calcareous, pelitic, semi-pelitic and psammitic rocks similar to those described by Shackleton (1946) from Maralal, Parkinson (1947) from the Mtito Andei-Tsavo area, Schoeman (1948) from the Kitui District and Searle (1952) from West Suk. It is a metamorphic series that has been altered in varying ways and degrees to rocks which, in places, reveal little or no evidence of their former character. In extensive areas of uniform metamorphic grade a classification of such heterogeneous rocks must be based on two genetic principles, first on the pre-metamorphic nature of the rocks involved, and second on the nature and cause of the modification of the metamorphic rocks by ultrametamorphism. The main agency causing the first stage of alteration of the rocks is dynamo-thermal metamorphism which involves "recrystallization or other chemical reconstitution of an essentially solid mass, not more than a small fraction of which at any given time, has consisted of the aqueous, liquid or gas phase through which such chemical reactions are thought usually to proceed" (Turner, 1948, p. 305). Ultrametamorphism involves principally the process of granitization, whether by permeation of alkali-rich fluids along selective channels, through pore spaces, or by injection of a granitic magma along planes of weakness.

The processes of granitization have been amply described by Schoeman (1951, p. 11) who considered that all of them are involved in the production of migmatites. The present writer, on the other hand, accepts Sederholm's (1923 and 1926) definition of migmatite and regards migmatization as a single restricted phase of granitization in

which the granitic component remains megascopically visible and traceable to a magmatic source. The granitic portion of the migmatite is regarded as having formed from a silicate melt containing a limited amount of water whereas aqueous solutions containing a limited silicate content are regarded as having been active in the production of veined gneisses from metamorphic rocks (Turner, 1948, p. 305). Veined gneisses are accordingly considered as products of normal regional metamorphism, permeation-gneisses as products of ultrametamorphism in which discrete igneous material (derived from a silicate melt) has been introduced on a microscopic scale, and injection-gneisses, whilst also products of ultrametamorphism, are regarded as the only true migmatitic rocks.

2. Calcareous and Calc-silicate Rocks

The calcareous rocks are represented principally by marbles, together with occasional hornblende-epidote gneisses and pyroxene gneisses. Owing to their resistance to weathering small marble outcrops are found on the summits of knolls and are there the only rocks types seen, their contacts and the contiguous rocks being covered by red sandy soil. Marbles are widespread throughout the area, indicating the sedimentary nature of the country-rock series as a whole. Their principal occurrence forms an integral part of the Ngarigaishi hills, the southern termination of which lies $1\frac{1}{2}$ miles south of the mapped area. The marble trends north-west and dips at 20° to the north-east; the maximum width of outcrop, occurring near Hill 4620, is 7,000 ft., which gives a calculated thickness of 2,300 ft. The base of the marble rests upon pelitic and semi-pelitic gneisses which are seen occasionally a little to the west of the area, but contacts on the eastern flank are obscured by red sandy soil.

The marbles are usually homogeneous in grain size, but in several places vary from coarse to medium-grained. They are often colour-banded, grey being dominant, though brown and green streaks and bands are caused by the presence of phlogopite and muscovite respectively. Chemically, they differ considerably over the whole area. At Mutini, for example, the analysis of the upper marble band shows an MgCO_3 content of between 1.5 and 4.3 per cent whereas the lower band contains approximately 33 per cent MgCO_3 . It is probable that the MgCO_3 , as is usual in such rocks, occurs in dolomite as well as in solid solution in the calcite.

Streaks and lenses of amphibolites containing garnet, diopside, hornblende and scapolite are conspicuous in the marbles of the Ngarigaishi Hills. Specimen 59/120A affords an excellent example of these lenses, some of which attain a length of 6 ft. The rock is greenish-grey in colour and speckled with irregular grey patches of scapolite. In thin section it is seen to consist of 80 per cent diopside, 18 per cent scapolite and 2 per cent hornblende. Scapolite occurs in large optically continuous plates enclosing and replacing diopside. In specimen 59/120B from another part of the amphibolite lens, hornblende is dominant over diopside whilst interstitial calcite, biotite and magnetite together amount to 10 per cent of the constituents. Other schlieren and lenses consist of assemblages of garnet-hornblende-plagioclase and garnet-diopside-epidote.

Specimen 59/119 from a point one mile south-south-east of Hill 4600 shows a "granite" vein cutting marble. The "granite" is separated from the marble by an outer zone of green diopside and an inner zone of black biotite, each one $\frac{1}{4}$ th of an inch in width. The biotite zone passes into biotite perthosite which is the principal rock type of the vein and is assumed to have resulted from the desilication of granite by reaction with the marble. The feldspars of the biotite perthosite are microcline-microperthite with large crystals of oligoclase. Irregular flakes of biotite occur either poikilitically enclosed in oligoclase or interstitially between the microcline-microperthite. Quartz is absent, whilst calcite and scapolite are accessories, the latter becoming prominent towards the biotite selvages where large optically continuous crystals are seen replacing plagioclase and biotite.

Although not within the map area a forsterite marble (59/136) was collected from the base of a small knoll close to the road at the northern end of Lake Amboseli. Forsterite occurs as small, blue, ovoid and translucent crystals, just visible to the naked eye. Diopside is also present in the rock whilst the calcite in specimen 59/131 shows remarkable micrographic exsolution of a second carbonate tentatively identified as dolomite. Shackleton (1946, p. 7) mentions the occurrence of forsterite occurring in dolomitic marbles from the Maralal District.

Small-scale mineralization is encountered in narrow zones in most of the marbles. In some instances it is associated with quartz lenticles whilst in most cases it appears to have resulted from the recrystallization of impurities within the original limestone. Graphite, in disseminated flakes, is the most common mineral and occurs in bands up to 2 ft. in width. Narrow bands and pencils of micaceous material are frequently observed as in specimen 59/98 from Mutini, where both green and brown micas occur in association with quartz. The brown mica ($\beta = 1.582$) has a sugary appearance and grades into a coarser and deeper brown phlogopite ($\beta = 1.595$). A bright bottle-green mica is associated with the phlogopite but also occurs alone elsewhere in the marble. Its refractive index is $\beta = 1.606$, which is higher than that of a normal muscovite. In thin section it exhibits a pale green colour and may be compared with an iron-rich muscovite. Other accessory minerals include pyrrhotite, iron pyrite, chalcopyrite, quartz and feldspar.

A pyroxene gneiss (specimens 59/19, 59/20 and 59/30), derived from an impure magnesian limestone, outcrops on flat ground $5\frac{1}{2}$ miles west of Sultan Hamud and, though its contacts are not visible, it appears to conform to the general strike of the area. The major part of the outcrop consists of a coarse-grained green rock speckled with black crystals of hornblende. Quartz and epidote in banded sequence are characteristic towards the edge whilst small quartz veins ramify through this zone. The following mineral assemblages were recorded in the thin sections: epidote-hornblende-plagioclase, epidote-diopside, diopside-epidote-hornblende-plagioclase and calcite-garnet-diopside. The green diopside is pleochroic and approaches omphacite, whilst the hornblende is strongly pleochroic from bluish-green to greenish-yellow. The feldspar is oligoclase-andesine.

An amphibolite of sedimentary origin (specimen 59/11) occurs just below the southern end of Kasebe. The rock is greenish-black and coarse-grained, containing stringers of quartzo-felspathic material. Scapolite, diopside and hornblende in approximately equal proportions are its principal constituents, together with a little accessory sphene.

3. Pelitic and Semi-pelitic Rocks

Whilst most of the rocks described below show signs of replacement of their constituent minerals in thin slices, no pronounced megascopical effects of granitization are visible and they are consequently regarded as purely metamorphic. Four types are recognized, (a) dark-grey, fine-grained, biotite gneisses as seen in the gullies at Kanamou Kidogo, (b) kyanite-garnet-mica schist as at Manone and Masembene, (c) kyanite-quartz schist at Kasebe and to the south-east of Musuriamboi, and (d) sillimanite-garnet-mica schist.

The modal composition of a typical garnet-biotite-gneiss (specimen 59/83) from the south of Kabaini is shown in Table I. The rock is homogeneous in grain size, shows well-developed schistosity and is rich in biotite. A thin section shows porphyroblastic red

TABLE I.—VOLUMETRIC MODAL COMPOSITIONS OF SELECTED ROCKS FROM THE BASEMENT SYSTEM OF THE SULTAN HAMUD AREA

		59/83	59/111	59/37	59/151	59/14	59/127	59/183
Microcline	.. ..	—	5	10	52	16	32	36
Oligoclase	.. ..	36	51	56	35	37	21	25
Quartz	.. ..	18	20	22	5	49	30	34
Garnet	.. ..	10	—	—	—	—	17	—
Biotite	.. ..	36	24	11	8	2	—	—
Muscovite	.. ..	—	—	1	—	—	—	5
			59/94	59/4	59/49	59/6	59/34	59/195
Microcline	.. ..		1	12	16	37	39	32
Oligoclase	.. ..		61	58	36	42	45	37
Quartz	.. ..		35	28	48	17	6	19
Garnet	.. ..		—	—	—	—	—	—
Biotite	.. ..		—	—	—	—	7	8
Muscovite	.. ..		3	2	—	4	3	4

59/83—Pelitic garnet-biotite gneiss. Kabaini.

59/111—Partly permeated biotite gneiss. 3 miles west of Meshanai.

59/37—Permeated streaky biotite gneiss. Masembene.

59/151—Permeation gneiss. 2 miles E. of Buziani.

59/14—Quartz-felspar granulite. 5 miles W. of Sultan Hamud.

59/127—Permeated garnet granulite. Ngarigaishi Hills.

59/183—Permeated quartz granulite. Road junction to Lengesim and Morogoti No. 1 bore-holes.

59/94—Veined gneiss (aplo-granite vein). Emali Tatu.

59/4—Veined gneiss. Nthukuni.

59/49—Veined gneiss. Kamumu.

59/6—Veined gneiss. Nthukuni.

59/34—Granitoid gneiss. Masembene.

59/195—Biotite granite. 3 miles W. of Kemiosa.

garnets enclosing both biotite and basic oligoclase. Quartz and accessory apatite are present.

Kyanite-garnet-mica gneiss (specimen 59/215) from Masembene is rich in greenish-black biotite and contains large scattered crystals of porphyroblastic garnet and blades of greenish-white kyanite.

The kyanite-quartz gneisses vary considerably in colour, coarseness of grain and the proportion of kyanite to quartz. Specimen (59/172) from south-east of Musuriamboi is white on fresh surfaces and has a sugary appearance. Under the microscope (Fig. 1A) it resolves into discontinuous bands of parallel crystals of kyanite, together with quartz and sericite. Magnetite and rutile are rare accessories. This rock is similar to specimen (59/217), from a kyanite occurrence $2\frac{1}{2}$ miles further north where kyanite-quartz schist outcrops on the northern flank of a knoll shown on the map. A chemical analysis of this kyanite and an estimate of its economic possibilities are given in Chapter VIII.

A kyanite-quartz schist with blades of kyanite measuring up to 2 in. in length and containing approximately 70 per cent kyanite, occurs as float on the eastern side of Kasebe hill. Although no outcrop can be seen, there is every possibility that a narrow band up to 10 ft. in width dips into the hill at this locality.

Sillimanite-garnet-mica schist (specimen 59/223) was found at the side of a dry water-hole two miles south-south-east of the Kajiado-Emali-Laitokitok road junction. The rock consists of augen of red garnet, plagioclase felspar, aligned streaks of black biotite and white feathery wisps of sillimanite. Thin sections (Fig. 1B) show that the

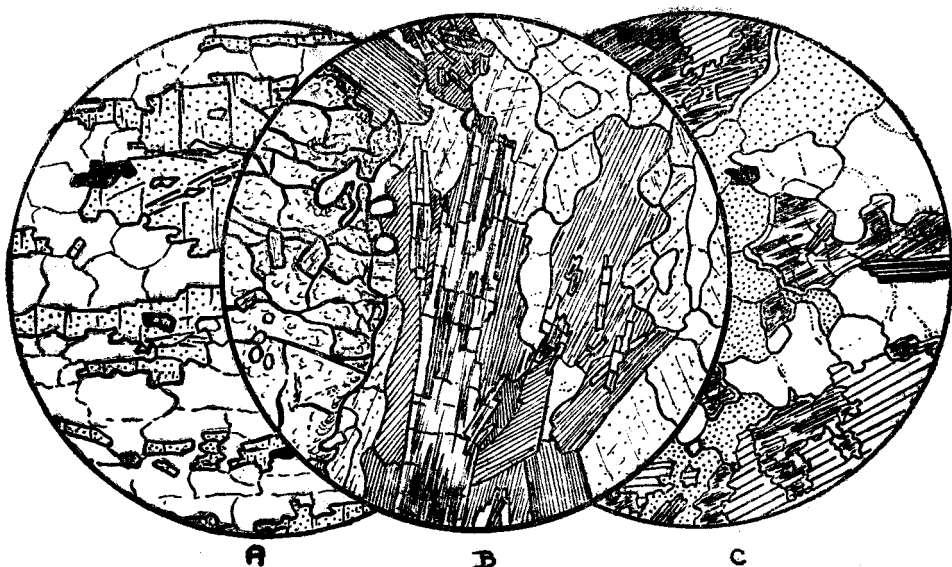


Fig. 1.—Drawings of thin sections of Basement System rocks from the Sultan Hamud area.

- A.—Kyanite-quartz gneiss, $5\frac{1}{2}$ miles south-east of Musuriamboi. Specimen 59/172, x22. The slide shows large prismatic and orientated crystals of kyanite (stippled) together with quartz (white), magnetite (black) and rutile (heavy outline).
- B.—Sillimanite-garnet-mica schist, 2 miles S.S.E. of the Kajiado-Emali-Laitokitok road junction. Specimen 59/223, x22. The section shows sillimanite enclosed in biotite (lined) together with porphyroblastic garnet (hackly surface), oligoclase (stippled), quartz (white) and apatite.
- C.—Muscovite-biotite granitoid gneiss, Selengai River. Specimen 59/154, x22. The rock comprises interstitial microcline (stippled) and muscovite (open lines), replacing oligoclase (shaded) and quartz (white). A narrow rim of albite has developed at the contact of microcline and oligoclase.

garnet occurs as large subhedral poikiloblastic crystals enclosing oligoclase, orthoclase and quartz. Sillimanite shows replacement by biotite, the former occurring as sheaves of fibres as well as small acicular crystals. The feldspar is a basic oligoclase showing only faint twinning, whilst quartz is present in small amounts.

Specimen 59/70 from the base of Lolondo is a semi-pelitic rock showing only faint signs of granitization. It is a finely banded rock with discontinuous bands of quartz and feldspar attaining a maximum thickness of a $\frac{1}{4}$ in., alternating with bands containing small disseminated flakes of biotite as well as quartz and plagioclase. Irregular garnets and small amounts of apatite are scattered throughout the rock.

4. Psammitic Rocks

Pure quartzites are absent, though micaceous types and some that are kyanite-bearing outcrop at Kemioso. They form an arcuate ridge 800 yd. in length, 50 ft. wide and, at the southern end, approximately 50 ft. in height, diminishing northwards to small outcrops. Kyanite-muscovite quartzite is the dominant rock type at the southern end whilst the central and northern portion consists of muscovite-quartzite.

A small quartzitic exposure lies near the south-eastern corner of the area and consists predominantly of interlocking quartz grains and minor amounts of microcline and sericite.

The greater portion of the psammitic rocks is represented by quartz-felspar granulites, which are often granitized and have a wide distribution over the area. A quartzo-felspathic granulite (specimen 59/14), with phenocrysts of magnetite, exhibiting a typical granulose texture with no signs of schistosity, was collected from an outcrop four miles west of Sultan Hamud. Microscopically it consists of semi-rounded, even-sized grains of quartz and oligoclase with a smaller percentage of potash felspar. Small ragged flakes of green biotite, an occasional pink garnet and sericite are accessories.

5. Carbonaceous Rocks

Graphite gneisses are rare, the principal outcrop measuring only a few yards in length and width, being situated $9\frac{1}{2}$ miles almost due south of Mutoroki bore-hole No. 2. Graphite occurs in flakes, up to a $\frac{1}{4}$ in. in diameter, disseminated evenly throughout the rock. Magenta-coloured garnets, colourless in thin section, are a common constituent, together with fine-grained aggregates of cloudy plagioclase felspars, perthitic microcline and clear quartz. Pyrite veining also occurs. Graphite flakes have also been brought to the surface from a recent bore-hole at Sultan Hamud.

6. Meta-intrusive Rocks

(1) META-PERIDOTITE

A small sill-like intrusion of an ultramafic rock outcrops on a spur $1\frac{1}{2}$ miles north-west of Lolondo. The rock is identical with a hypersthene peridotite described from West Suk (Searle, 1952, p. 19). Small fragmentary grains of olivine are enclosed poikiloblastically by large plates of hypersthene into which acicular and prismatic crystals of actinolite penetrate. Large irregular garnets, as well as smaller rounded crystals, are common. A rough estimate of the composition of specimen 59/72 gave:—

							%
Olivine	..	..	..	..	..	..	3
Hypersthene	..	..	..	..	..	..	40
Actinolite	..	..	..	..	..	..	42
Garnet	..	..	..	..	..	..	15

The edge of the intrusion is finer-grained and foliated, with a greater development of interlocking prisms of actinolite. Here only fragmentary grains of the original hypersthene remain, as it has been largely replaced by gedrite and magnetite, whilst actinolite still continues to replace both the hypersthene and the gedrite (specimen 59/71).

(2) META-DOLERITE

This rock type, represented by specimen 59/75, forms a 30 ft. sill situated several yards above the meta-peridotite described above. It is a coarse-grained speckled black and white rock, with large unorientated pseudomorphs after plagioclase, and scattered red garnet. Hornblende, plagioclase, diopside, garnet and zoisite are the chief components, the diopside often forming optically continuous rims to the hornblende. Garnet is irregular in both shape and distribution, the larger crystals showing well-developed sieve-texture. Felspars that have not been pseudomorphosed by zoisite are slightly zoned basic andesines, measuring up to 3 mm. in length. Zoisite is the most common of the accessory minerals except where it takes the place of plagioclase in which case it becomes an essential constituent. It is confined to areas of plagioclase felspar. A little bluish-green pleochroic hornblende is associated with the garnet, whilst epidote granules occur in association with hornblende and garnet.

All the felspar has been replaced by zoisite in specimen 59/76, the larger crystals attaining a length of 3.5 mm. Poikiloblastic texture is well developed, the inclusions consisting of hornblende and, to a lesser extent, of sphene. Garnet also shows considerable development of the same texture.

(3) META-GABBRO

A highly-altered gabbroic rock (specimen 59/189) from a point approximately seven miles along the road south-west of Selengai, is reminiscent of the metagabbro from Kaptumet, West Suk (Searle, 1952, p. 44). In a thin section the rock appears to have been almost completely recrystallized. The hypersthene is faintly pleochroic and appears in ordinary light to be one homogeneous crystal, though it actually consists of numerous individual crystals with haphazard optical orientation. Augite appears to have resisted recrystallization, though like the hypersthene it has suffered considerable replacement by uralitic hornblende in which it is completely encased. The plagioclase is labradorite, translucent and highly twinned, but with innumerable small inclusions of uralite which are concentrated along the twin planes and render them visible even in ordinary light. Small vermicules of pleonaste lie scattered throughout the uralite and together with sphene and magnetite form the principal accessory minerals. An approximate visual estimation of the mineral components is—

						%
Hypersthene	..	..	..	..	..	25
Augite	..	..	..	..	..	4
Uralite	..	..	..	..	..	35
Plagioclase	..	..	..	..	..	34
Pleonaste and accessories	..	..	..	..	..	2

(4) AMPHIBOLITES

Amphibolites derived by the metamorphic alteration of doleritic intrusions are not abundant and most of those encountered measure only a few feet in thickness. They differ from the meta-dolerite in their distinct foliation and uniformity of composition. Specimen 59/88 from the southern end of Kabaini ridge may be taken as representative of this type. It is a fine-grained foliated rock consisting of equal parts of hornblende and plagioclase. Hornblende, occurring as irregular prisms, is pleochroic with X = pale greenish-yellow, Y = olive-green and Z = blue-green; in places it has altered to biotite. The plagioclase is a basic oligoclase occurring as interlocking equigranular crystals free from inclusions but with occasional blebs of quartz and irregular prismatic grains of epidote and sphene.

A garnetiferous amphibolite (specimen 59/63), 40 ft. in thickness, occurs at the northern end of the spur one mile north of Mutini. It differs from most amphibolites by containing a high percentage of microcline, which predominates over sericitized plagioclase, and by the presence of garnet and zoisite. It is cut by numerous quartz veins which, together with the presence of microcline, suggests that the rock has been metasomatically altered.

(5) ASBESTOS, TALC AND ACTINOLITE ROCKS

A brownish-yellow, soft, talcose rock containing pseudomorphosed relics of gedrite occurs in association with the amphibolite (specimen 59/63) described above. The talc rock forms a 120-ft. band interleaved between two 40-ft. bands of amphibolite. The high degree of granitization sustained by the amphibolite is also responsible for the alteration of fibrous gedrite into talc. Pits have been dug into the talcose rock but no change in its nature occurs with depth.

An actinolite rock (specimen 59/80), consisting of interwoven rosettes of bright green actinolite, was found along the spur connecting Kabingi with Kabaini. A thin section shows interpenetrating prismatic crystals, up to 4 mm. in length, of very pale green actinolite with rare inclusions of magnetite granules.

7. Permeation-gneisses

Microscopic evidence from the area described in this report indicates conclusively that metasomatism and replacement of the original metamorphic rocks by permeating fluids has been operative on a large scale. The rocks resulting from permeation by extraneous magmatic fluids are here termed permeation gneisses. Since the process is essentially one of feldspathization and is directed towards the production of a homogeneous granitic rock the term "granitization" has been applied to it.

H. H. Read (1931, p. 143) stated that permeation gneisses have a clear sedimentary habit in the field. This is confirmed in the present area, but in place of Read's soda-metasomatism in which oligoclase has been added to the sedimentary rocks, potash-metasomatism has occurred. In the well-known migmatite areas of Scotland and Fennoscandia microcline is noticeably absent, whilst oligoclase and myrmekite are dominant, whereas in Kenya microcline often equals and sometimes exceeds oligoclase in amount. Myrmekite is noticeably rare. In the Sutherland migmatite complex (Read *op. cit.*) the introduction of potash is seen in the occurrence of white mica and in the formation of prehnite and chlorite at the expense of biotite. In Kenya we are undoubtedly dealing with a more intense form of metasomatism in which the soda phase was superseded by one of potash metasomatism. It is not known to what extent soda has been added to the original metamorphic rocks but, judging from the occurrence of porphyroblasts of oligoclase and the ubiquitous nature of this mineral in nearly every rock type, considerable amounts of soda must have been added. The same argument applies to the potash in the form of microcline. Quartz is considered to have been emplaced in either or both of two ways—as a rheomorphic product of the metamorphic rock or during hydrothermal stage of the soda metasomatism. Microcline is definitely the last mineral to have formed and occurs in ever-increasing amounts as the rocks approach granite in constitution. It will be seen that the original nature of the metamorphic rocks has been changed considerably by the activity of the two phases of metasomatism.

Texturally the changes are marked by the coarsening of grain size, which in places becomes pegmatitic, by the destruction of the finely banded and laminated rocks with the development of streaky, speckled and highly contorted gneisses and, eventually, by the development of homogeneous granitoid gneisses.

An attempt is made below to show the progressive stages of granitization in the major types of country-rock. It is difficult to trace changes along the strike in any particular locality and consequently comparison has been made with rocks collected from scattered parts of the area.

(1) GRANITIZATION OF CALC-SILICATE ROCKS

The limestones are not as a whole affected by granitization, though sections of some specimens contain blebs of quartz, oligoclase and microcline which may represent introduced material. The principal types of calc-silicate rocks formed through the agency of granitization are represented by hornblende-plagioclase-epidote-gneisses. Specimen 59/73, from the northern end of Kabaini hill, is a leucocratic, coarse, grey rock with relic bands comprised of hornblende, garnet and epidote. The garnet exhibits a mottled brownish-red and pink colouring, the deeper colour being prominent at the periphery and around inclusions. Epidote occurs as small grains often embedded in quartz and plagioclase feldspar. Quartz varies considerably in grain size and has sutured margins against the other constituents; it is in excess of oligoclase.

Specimen 59/74, also from Kabaini, is a streaky hornblende-garnet granulite, in which the feldspathic portion is dominant. Hornblende is pleochroic from yellowish-green to deep blue-green and is much corroded by quartz. The feldspar is labradorite, but an occasional crystal of basic oligoclase occurs interstitially. Quartz forms small semi-rounded grains and also large poikiloblastic crystals enclosing the earlier formed quartz and plagioclase. Garnet is rare, whilst epidote is confined to only a few bands.

A more advanced stage of granitization is represented by specimen 59/228, from near the summit of Soysambu. It has a glassy appearance and consists of scattered hornblende, epidote and garnet in a base comprising quartz and oligoclase.

(2) GRANITIZATION OF PELITIC AND SEMI-PELITIC ROCKS

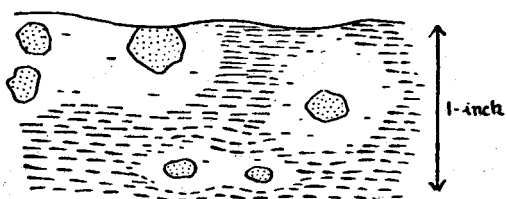
A partly permeated pelitic biotite gneiss is represented by specimen 59/111, from the base of a hill to the north of Lake Amboseli (not shown on map). Megascopically it shows white orientated porphyroblasts of oligoclase measuring up to 8 mm. in length, embedded in a dark fine-grained matrix rich in biotite and quartz. In thin section large porphyroblastic crystals of oligoclase can be seen expanding against the contiguous biotite flakes which lie with their (001) faces parallel to the peripheries of the feldspars. Plagioclase is the dominant leucocratic mineral and forms the major part of the granoblastic groundmass. Strain polarization in quartz and the slight curvature of the albite twinning of the feldspars indicates that movement of the rock occurred subsequent to granitization.

An early stage of feldspathization in a semi-pelitic rock is seen in specimen 59/213 from Itororto. The hand-specimen is remarkable for the clear way in which it demonstrates metamorphic diffusion (Fig. 2A). Garnets measuring three-tenths of an inch in diameter are surrounded by leucocratic aureoles, often as much as three-quarters of an inch across, consisting of quartz and oligoclase with only an occasional flake of biotite. Outside the aureoles normal biotite-quartz-feldspar relationships exist. With increasing metamorphic differentiation one would expect an even greater aureole around the growing garnets. A thin section of another permeated pelitic gneiss from Itororto shows a structure similar to that of specimen 59/111, with ragged greenish-brown biotite flakes enveloping lucid porphyroblastic crystals of oligoclase (Fig. 3B). The matrix in which the porphyroblasts lie comprises an irregular mosaic of turbid plagioclase, quartz, interstitial potash feldspar and biotite. A little muscovite and iron ore is present.

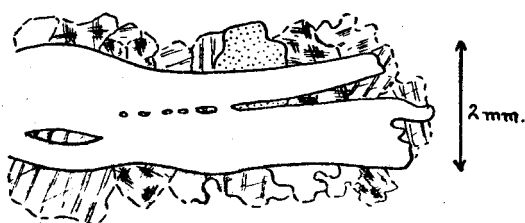
A streaky augen-gneiss, specimen 59/84 from a gully north of Kanamou Kidogo, represents the next stage in the granitization of the pelitic rocks. The augen attain a length of 1 in. along their longer axes and $\frac{1}{2}$ in. along their shorter axes and are surrounded by flakes of biotite. A few small scattered garnets are visible in the hand-specimen but were not cut by the thin section. The rock consists predominantly of large blebs of quartz and large anhedral grains of partly turbid oligoclase. Potash feldspar has infiltrated along the interlocking crystal boundaries and is separated from the oligoclase by a narrow zone of clear albite. Muscovite is seen replacing biotite especially along the cleavage planes; it also forms an important secondary mineral in the oligoclase.

A completely soaked permeation gneiss is represented by specimen 59/175, from a small knoll half a mile south of Musuriamboi. It is impossible to distinguish in the hand-specimen between introduced and host material, so intimately are the two related. Pink grains of potash feldspar, occasionally porphyroblastic, are embedded in a fine-grained grey groundmass of oligoclase, quartz and biotite. Rare foliation planes are black with small platy crystals of biotite. Thin sections show large partly resorbed crystals of oligoclase sometimes enclosing quartz blebs, surrounded by a granular mosaic of sericitized oligoclase, clear quartz, microcline, scattered flakes of greenish-brown biotite and colourless muscovite. The rock has lost most of its banded appearance.

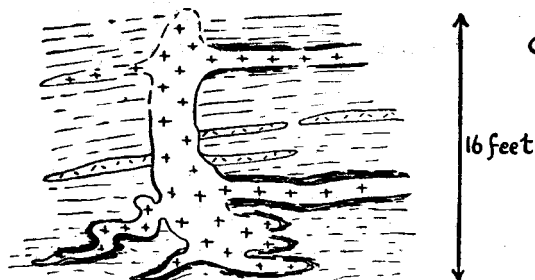
Specimen 59/37 from Masembene is a streaky permeation gneiss with large areas of white quartzo-feldspathic material in which are embedded irregular streaks of coarse biotite flakes. It is noticeable that with increasing granitization biotite decreases in amount but increases in grain size. The mode of the rock is given in Table I and a sketch of the thin section in Fig. 3C.



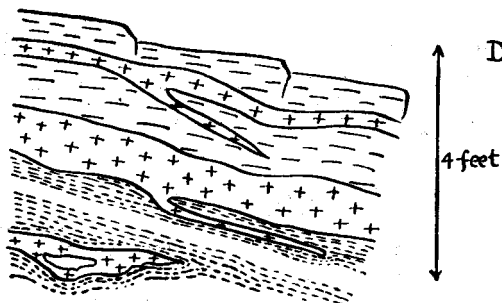
- A. A.—Felspathized semi-pelitic gneiss showing the effects of metamorphic diffusion. Specimen 59/213, Itororto. Small garnets are surrounded by an aureole rich in quartz-felspathic material, whilst the remainder of the rock is rich in biotite.



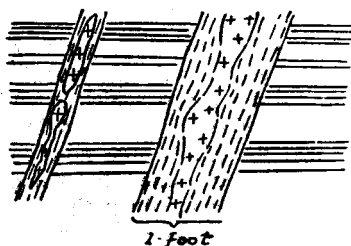
- B. B.—Replacement vein in quartz-felspathic granulite. Specimen 59/191, Tolokera. An optically continuous quartz crystal replaces garnet (stippled), microcline, oligoclase and quartz.



- C. C.—Segregation veins, Selengai River. Replace aplogranite vein with biotite selvages occurring in a biotite granitoid gneiss.



- D. D.—Replacement veins, Selengai River. Granite pegmatite consisting of quartz, oligoclase and scattered microcline-microperthite replacing biotite granitoid gneiss and banded biotite gneiss.



- E. E.—Flow-lining in a transverse fracture, Selengai River. Granite pegmatite veining occurs along the centres of fractures in which the foliation of biotite flakes in the host granitoid gneiss trends perpendicularly to the normal direction of foliation.

Fig. 2.—Minor structural features in Basement System rocks of the Sultan Hamud area.

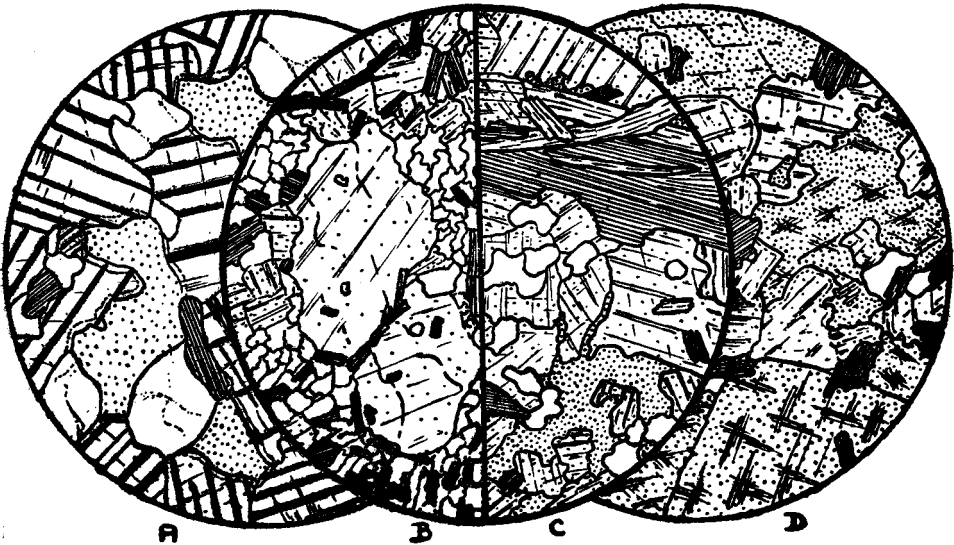


Fig. 3.—Microscope drawings of thin sections of permeation gneisses from the Sultan Hamud area.

- A.—Psammitic permeation gneiss, Tor 5, 10 miles S.S.W. of Emali Station. Specimen 59/157, x50. The slide shows predominant oligoclase feldspar with interstitial and replacive grains of microcline (stippled).
- B.—Pelitic permeation gneiss, Itororto. Specimen 59/213, x50. The initial stage of soda-metasomatism is represented by porphyroblastic crystals of irregular oligoclases.
- C.—Pelitic permeation gneiss, Masembene. Specimen 59/37, x50. An intermediate stage in the permeation by alkaline pore fluids in which microcline (stippled) and muscovite (open lines) are seen replacing oligoclase and biotite respectively.
- D.—Pelitic permeation gneiss, 2 miles south-east of Buziani. Specimen 59/151, x50. The slide illustrates the final stage of permeation by potash-rich fluids in which microcline becomes predominant. Quartz (white) has almost disappeared, whilst sericitized oligoclase with albite rims occurs in a highly-corroded state. The original alignment of the biotite has now been destroyed.

The most advanced stage of feldspathization is represented by specimen 59/151 (Fig. 3D) from a point $2\frac{1}{2}$ miles south-east of Buziani. The biotite has been reduced to small clusters in original foliation planes giving the rock a mottled black and white appearance. The mode is given in Table I where it will be seen that potash feldspar has now become dominant and that quartz and oligoclase are much reduced.

(3) GRANITIZATION OF PSAMMITIC ROCKS

Outcrops of feldspathized granulite are found in widely dispersed parts of the area and of the few rock outcrops in its southern half nearly all are of this type. The Emali hills, south of Sultan Hamud, belong predominantly to this group, which extends north-eastwards to beyond Kwangi I where outcrops are considerably reduced in size. The preponderance of this rock type does not imply that the whole area now covered by alluvium and red sandy soil consists of granulitic rocks, but rather that the granulites, being more resistant to weathering, remain as small outcrops whilst the less-resistant pelitic and semi-pelitic rocks have suffered greater erosion and are now covered by recent deposits.

Felspathized granulites are difficult to distinguish in the hand-specimen from the unfelspathized granulites described previously. Like them they are hard, compact, quartz-rich, buff-coloured rocks, often containing scattered red garnets and showing only faint banding. Megascopical signs of replacement are seen in the almost ubiquitous quartz schlieren, which often attain a length of several inches and a width of only a few millimetres. In specimen 59/191 from the summit of Tolokerai, quartz veins are clearly visible, ramifying and bifurcating along the general direction of foliation. The replacive nature of these veins is further emphasized in thin section (Fig. 2b).

Early stages of granitization may be attributed to the introduction and recrystallization of quartz either as small individual semi-rounded grains of even distribution (specimen 59/17) or as much larger grains with highly sutured margins. The remainder of such rocks consists of an equigranular mosaic of orthoclase, turbid plagioclase and quartz. A little microcline occurs interstitially along the crystal boundaries. Irregular flakes of muscovite also occur and sometimes enclose other minerals poikiloblastically (specimen 59/17).

A further modification of the granulites is caused by the segregation of quartz into irregular lenticular bodies with their longer axes parallel to the strike of foliation (specimens 59/127, 59/183). In specimen 59/191, the host-rock, lying between quartz schlieren, consists of microcline with smaller amounts of oligoclase and iron ore. All the quartz appears to have found its way into the quartz lenticles. Concurrent with quartz segregation, or immediately after it, microcline-micropertite in which blebs of albite are conspicuous is formed. Oligoclase becomes increasingly turbid and resorbed and is separated from the microcline by a narrow but clear rim of albite. The rocks as a whole become coarser in grain size. The next stage is the formation of porphyroblastic microcline feldspars which have diverted, and occasionally replaced, the quartz schlieren in places where the quartz veining is well developed. Iron ore becomes a common accessory mineral.

Further granitization processes are illustrated by specimen 59/157 from Tor 5, 10 miles S.S.W. of Emali Station, which represents the end-stage of soda-metasomatism (Fig. 3A). It contains less potash feldspar than specimens 59/127, 59/183 and 59/191 and notably less quartz, but much more oligoclase which, unlike previously described oligoclase, is lucid and only partly sericitized. Small quartz crystals are embedded in both plagioclase and microcline. Albite rims around the oligoclase are well developed where it is in contact with the microcline. Any garnet that may have been originally present is now represented by scattered flakes of biotite.

Garnet is a common mafic mineral in these permeation-gneisses though it often occurs in a corroded state, and in specimen 59/17 is partly replaced by muscovite. Deep green hornblende, small grains of epidote, biotite and secondary iron ore are often accessory minerals.

The origin of the quartz in the quartz schlieren calls for special comment. It appears to have been derived from the rock in which it occurs since, with increasing amount of quartz veining, the quartz of the host-rock diminishes. Its habit is clearly that of molecular replacement as can be seen from Fig. 2b and its elongation has been controlled by forces acting upon the granulites during the time of its formation. There is ample evidence in the presence of microcline to show that felspathization had already reached a relatively advanced stage. Later felspathization in the form of porphyroblastic microcline may have been induced by a later phase of magmatic injection.

(4) GRANITOID GNEISSES AND MIGMATITIC GRANITE

There are three principal methods whereby granitoid gneisses can be distinguished in the field. Firstly they usually outcrop as tors, with massive jointing and the boulder

appearance typical of granite weathering. Secondly the rocks are leucocratic and homogeneous both in texture and mineral composition, with the homogeneity occurring over a broad area usually measurable in yards, and thirdly they grade imperceptibly into the country rocks. The term also implies that they are derived by the *granitization in situ* of sedimentary rock and that in no instance are they intrusive. The migmatitic granites, on the other hand, are coarser in grain size, have porphyritic crystals of feldspar, and exhibit no orientation of their components. They are sometimes discordant with respect to the country-rocks.

Granitoid gneisses are of two kinds, some containing biotite and others in which biotite and muscovite are present. Specimen 59/34 (Table I), from Masembene, is a typical biotite granitoid gneiss. It is a fine-grained white rock speckled with small flakes of biotite which give it a well-marked foliation. No signs of any original bedding or banding are visible. In thin section albite rims are well developed around the sericitized oligoclase, and microcline has increased from being an interstitial mineral to a coarse aggregate enclosing and replacing both quartz and oligoclase. Biotite is often partly replaced by muscovite along cleavage planes and around the periphery. Apatite and iron ore are present.

Nearly all the granitoid gneisses exhibit the same relationship between their principal mineral components—quartz, oligoclase and microcline. The oligoclase occurs as highly-corroded crystals of varying grain size usually grouped in small clusters. The intervening material is mainly microcline of varying grain size, showing a strong replacive relationship towards the other minerals. Quartz occurs as corroded crystals and was obviously at one time more abundant than at present. Sericitization reaches various stages, ranging from slight replacement of the plagioclase and biotite to the formation of large poikiloblastic plates, as in specimen 59/154 (Fig. 1c) from the Selengai River, 2½ miles south of Mashuru dukas. The rarer muscovite-rich granitoid gneisses are usually found as bands of varying width trending conformably in pelitic biotite gneisses. They probably represent a zone of penetration of metasomatizing fluids which have reacted with the adjacent host-rock.

Specimen 59/153, from a boulder 2½ miles south-east of Buziani, represents a migmatitic granite. In hand-specimen no orientation is seen of the constituents, which occur as phenocrysts of pink and white feldspar up to ½ in. in length, unevenly distributed in a groundmass of quartz, feldspar and biotite. Oligoclase is dominant, occurring both as phenocrysts and as a major part of the groundmass. Albite rims again are found where the oligoclase is in contact with microcline. Biotite occurs as relic flakes enclosed in quartz and plagioclase.

A biotite granite is represented by specimen 59/195 (Table I), from a small hill-top exposure five miles north-west of Ususu. Its relationship to the surrounding rocks was not seen owing to a covering of red sandy soil. The rock is rich in unorientated flakes of biotite and contains small scattered phenocrysts of pink microcline and white oligoclase. The plagioclase shows replacement by quartz, both, in turn, being replaced by microcline and microcline-micropertthite. The margins of albite rims developed around oligoclase grains where it is adjacent to microcline are highly sutured. A small amount of myrmekite is present though it is not extensively developed in these rocks. Muscovite replaces biotite and occasionally forms large interstitial plates.

8. Veined Gneisses

Rocks of this type are widely distributed throughout the area and occur in association with all the previously described rocks. They consist of associations of quartzofeldspathic lenses, schlieren and streaks, which are often pegmatitic, and biotite gneiss, with the veins occurring either as regular alternating bands or as contorted veins and segregations often with a cross-cutting relationship. The term "veined gneiss" is applied non-genetically since the veins may have arisen from original differences in composition of

the pre-metamorphic rocks, by metamorphic differentiation or segregation, or they may represent channels along which successive metasomatizing fluids have passed. They show no visible connexion with an igneous intrusion. If the veins consist essentially of granitic or granodioritic material and can be demonstrated as originating from a granitic source the rocks are classified as injection gneisses and grouped with the migmatites.

The veins are coarse-grained and better studied in the field than in hand-specimen or thin section. Field examples are shown in Figs. 2 and 4. Their transgressive relationships are often obvious, whilst others vein and ramify along the cleavage and foliation

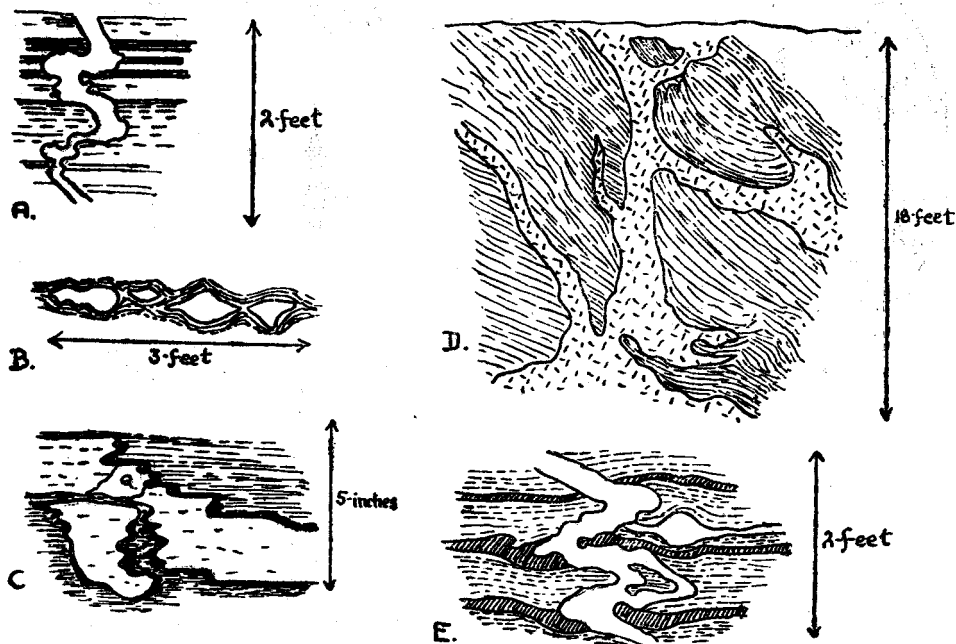


Fig. 4.—Minor structural features in Basement System rocks in the Sultan Hamud area.

- A.—A replacive quartz-oligoclase vein in banded biotite gneiss, Mashuru dukas.
- B.—Boudinage structure, in which quartz segregations are enveloped by a biotite-rich rim, Mashuru dukas.
- C.—Metasomatic replacement of biotite gneiss (close lines) by quartz and plagioclase and later by microcline giving a uniform coarse-grained granitoid gneiss with patches of quartz (Q) and biotite-rich selvages, Kamumu.
- D.—Injection gneiss, Karibani. The contacts of the injected vein are fine-grained and aplitic whereas the centres are pegmatitic and in this case contain workable deposits of mica.
- E.—Quartz-plagioclase segregation vein in banded biotite-gneiss, Kamap.

planes. It is often not possible to map the veins independently and where they are of large size they have been included with the quartzo-felspathic gneisses regardless of the country-rock in which they occur. Discordant veins often pass imperceptibly into concordant veins, showing that not all banding in the gneisses is due to original bedding. In general, bands or lenses which are devoid of a conspicuous biotite selvage, and generally parallel the foliation, may be regarded as original sedimentary structures that had been emphasized by the high degree of metamorphic differentiation consequent upon a high grade of metamorphism. Segregation pockets and lenses, boudinage structures and channels of permeating fluids, are often accompanied by a biotite-rich selvage.

Petrologically the veins of the veined gneisses are of three types: those in which only quartz occurs, those in which oligoclase is dominant and finally those in which potash felspar is conspicuous. Specimens 59/4, 59/49 and 59/94 are coarse, sometimes porphyritic, white rocks with only scattered flakes of biotite. Oligoclase is the most



Fig. 5.—Drawings of thin sections of Basement System rocks from the Sultan Hamud area.

- A.—Garnet-biotite-gneiss, from water-hole, 2 miles N.W. of Lengesim bore-hole. Specimen 59/184, x22. The slide shows an elongated quartz crystal replacing a semi-pelitic host-rock. Note the replacive nature of the quartz in relation to garnet (stippled), plagioclase (striped) and early quartz (white).
- B.—Quartzo-felspathic-gneiss, N. Tor, Mashuru. Specimen 59/147, x22. The diagram shows the final stage of soda metasomatism in which quartz becomes prominent replacing all previous constituents. This stage is followed by the introduction of potash-rich fluids which in turn replace all other constituents. Microcline (stippled) and muscovite (open lines) are shown replacing quartz (white) and plagioclase (shaded).
- C.—Vein in veined biotite gneiss, Kamumu. Specimen 59/49, x22. The slide shows fresh plagioclase, partly corroded by quartz with a little interstitial microcline (stippled).

abundant mineral except in specimen 59/49 (Fig. 5c), where quartz is dominant. The oligoclase occurs as lucid irregular crystals showing replacement by quartz, and a little microcline is occasionally present as an interstitial replacive mineral. Oligoclase becomes sericitized and decreases in amount in rocks in which microcline is predominant. Myrmekite is also developed in the quartz-oligoclase rocks but is never abundant. Muscovite increases with an increase in potash felspar and occurs as sericitic flakes in oligoclase and also as porphyroblastic crystals. A small amount of ragged biotite, pleochroic from straw-yellow to very dark brown, is also present.

The sequence of chemical changes noted in the veined gneisses, namely the initial influx of soda followed by a hydrothermal or aqueous stage in which quartz replaced oligoclase and finally the incoming of potash metasomatism, is in accordance with the chemical changes described in the host-rocks. It is suggested, therefore, that the majority of the veins of the veined gneisses represent channels along which active metasomatizing fluids passed, and that it was from these channels that much of the metamorphic rocks received their soda and potash. It is considered that two-way diffu-

sion operated during the metasomatism and that elements such as Ca, Fe and Mg were driven from the host-rock towards the replacive zone. This would account for the biotite-rich selvages which often occur at the contact of the host-rock with the veins.

9. Injection-gneisses

It is considered that the area does not represent part of an injection complex, in which the metamorphic rocks were subjected to replacement or assimilation by a granitic magma, although occasional granite veins, rich in microcline and muscovite, suggest the proximity of such a magma at depth. Specimen 59/147, from Mashuru, is a pink granite vein occurring in granitoid gneiss and cutting across the foliation at a low angle, with a discontinuous and narrow biotite selvage. The vein itself is rich in microcline with only small amounts of quartz and plagioclase. Microcline is also evident outside the vein where it has broken through its biotitic rim and has metasomatized the host-rock, replacing the original oligoclase, quartz and biotite. Muscovite is present in small amounts.

10. Pegmatites

Two types of pegmatite are recognizable; concordant pegmatites which have arisen through metamorphic differentiation, and discordant pegmatites which have developed largely by metasomatic process. The former consist essentially of oligoclase, quartz and biotite and have been described above as one of the types of vein in the veined gneisses. The latter, with a preponderance of microcline, are much coarser in grain size.

Segregation pegmatites are ubiquitous throughout the area, though they occur in greater abundance around the knolls north-west of Kiasa, where leucocratic muscovite-biotite gneisses pass laterally into pegmatite gneisses and eventually into narrow muscovite pegmatites. "Books" of mica up to $\frac{1}{2}$ in. thick and $1\frac{1}{2}$ in. in width are embedded in a matrix of oligoclase, quartz and occasional microcline. These pegmatites occur in an area of intense potash metasomatism and are in close proximity to some white quartz veins.

Several large excavations have been made into the hillside east of Ususu from which considerable amounts of mica have been recovered. At one pit the country-rock, consisting of granitized quartzo-felspathic gneiss and biotite gneiss, is penetrated by an ovoid pegmatite 30 ft. in width and 70 ft. in length. A rudimentary zoning of the constituent minerals was noted, quartz being adjacent to the wall-rock, followed inwards by a narrow 2-ft. zone of quartz and mica, finally passing into a central zone consisting predominantly of perthite and mica. This zonal arrangement, which is the converse of that usually found in pegmatites, is attributed to the late-stage of potash metasomatism which was prodigious in this part of the area. It is assumed that a quartz vein was in existence prior to the introduction of potash and that with its introduction much of the quartz was replaced giving rise to the rudimentary zonal arrangement. Other pegmatites in the neighbourhood show similar mineralogical arrangements. During mining operations several large crystals of beryl, measuring up to 6 in. in diameter, were discovered though none was found during the present survey.

Kwangi I and Kwangi II are two other mica pegmatite localities that have been worked. Two pits have been dug at Kwangi I, one a large oval excavation, 25 ft. deep and 120 ft. in length, the other a smaller trench-like pit noted for its preponderance of tourmaline crystals enclosed in quartz. The pegmatite of the larger pit trends north-south and dips steeply to the west. Greenish-white muscovite mica occurs near the centre of the pegmatite and is associated with massive pink microcline-micropertthite and quartz. Black partly vermiculitized biotite mica, is common towards the periphery. Garnet is a common mineral in the smaller pegmatites at Kwangi II. It occurs as large glomeroporphyrific aggregates measuring over 1 ft. in diameter, in which a few crystals showing combinations of dodecahedron and trapezohedron faces attain a diameter of 3 in.

A large excavation has been made in a pegmatite on the eastern flank of Karibani hill. A diagrammatic section is shown in Fig. 4D where the intrusive nature of the pegmatite is clearly demonstrated. The host-rock is highly contorted biotite gneiss, the biotite being secondary after hornblende derived from an original plagioclase amphibolite.

In all the pegmatites the order of crystallization appears to have been quartz, quartz + garnet + tourmaline + biotite, microcline-micropertthite + muscovite. Specimen 59/31, from Kwangi II, contains small garnets enclosed in 3 in. long crystals of tourmaline, which in turn are embedded in large books of greenish muscovite mica. Some specimens contain white muscovite surrounded by vermiculitic biotite; the significance of this is not known, but it is suggested that the two minerals may be intergrown and not replacive. Most of the muscovite has inclusions of red iron oxides and black manganese oxides, and careful trimming is necessary to obtain clear samples.

V—QUATERNARY VOLCANIC ROCKS

1. Introduction

The volcanic rocks which form the Chyulu range of hills south of Kibwezi continue north-westwards from that range into the Sultan Hamud-Emali area, where they form large isolated conical hills. The most westward manifestation of the volcanic activity occurs at the trigonometrical beacon of Buziani, which is a dome-shaped cinder cone rising to a height of 5,600 ft. and forming a distinct topographical feature. Comparable volcanoes, notable amongst which is Mwani, extend for a short distance north of the area into the Machakos District.

The most prominent volcano is Kiasa (5,990 ft.) which dominates the landscape for miles around and is distinguishable from as far south as the Tanganyika border. It is an isolated volcano and has a conical appearance when viewed from the south. On closer inspection from the northern side it is seen that the rim of the crater is at the base of the hill on its north side, and rises gradually to the highest point—conveniently marked by an acacia tree—on the western side. Like all other volcanoes in the area it is a cinder cone composed predominantly of volcanic ash and breccia with large boulders of highly scoriaceous reddish-brown lava, which are sometimes irregular and twisted, and sometimes bomb-shaped. Mwani, Kanamou and Ususu, the latter containing a small crater lake, are other prominent volcanic vents. Many smaller volcanoes occur to the east of the Emali-Laitokitok road, none attaining a great height and all composed of volcanic ash and breccia.

Explosions during eruptions must have reached considerable proportions since ash has been found nine miles from the nearest volcano. Erosion has undoubtedly removed much of the incoherent ash from areas of high ground, whilst black cotton soil overlies it in areas of low relief.

The occurrence of lava in the Buziani, Kwawatingila and Errui rivers and at the base of the volcanic succession in the Sultan Hamud valley suggests that the volcanic activity began with the eruption of lava which flowed into, and collected in, pre-existing valleys. The early expulsion of lava was followed by an extensive eruption of pyroclastics with only an occasional extrusion of lava. It is not known from which vents the lower lavas emerged, though isolated lava outcrops, in some cases many miles from similar outcrops, represent the sites of original volcanic orifices. These blisters of lava form small knolls, often less than 30 ft. in height, as at Kamavir, Buthane and Meshanai (a trigonometrical beacon north of Lake Amboseli).

Minor intrusives associated with the volcanic phase are rare. Three 2 ft. wide vertical dykes composed of highly vesicular lava with chilled margins occur at Vent I, $2\frac{1}{2}$ miles S.S.W. of Emali Station, whilst two fine-grained basaltic dykes cut the sides of Vent II, $6\frac{1}{2}$ miles south of Emali Station.

Although no evidence was found that these vents occur along a line of crustal weakness there is little doubt that their eruption was instigated by crustal movements in the underlying country-rocks.

No precise age is attributed to these volcanic rocks. Bore-hole records reveal the presence of old land surfaces at the base of the succession and at varying intervals from the base to the present surface. Those in the succession may represent no great time-lag since only a few years would be required to produce a weathered zone from newly-formed lava and ash. Their fresh appearance and lack of denudation, their similarity to the rocks of the volcanic hills north of Mount Kenya and in the Rift Valley, together with their chemical composition, are criteria favouring a Quaternary age for these volcanic rocks.

2. Stratigraphy and Petrography of the Volcanic Rocks

The succession at Mwani near Sultan Hamud (Fig. 6), the southern half of which appears on the map of the area is as follows:—

5. Upper olivine basalt.
4. Volcanic ash.
3. Volcanic agglomerate, ash and tuff with interbedded lava.
2. Agglomerate containing boulders of gneiss.
1. Lower olivine basalt.

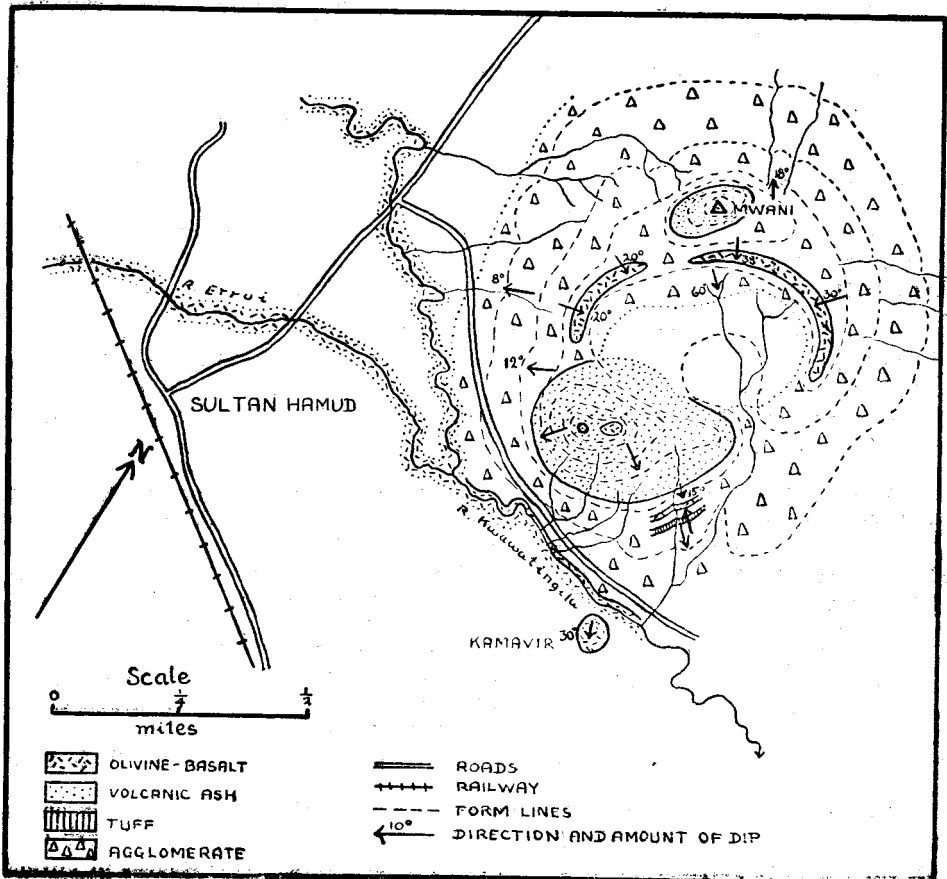


Fig. 6.—Geological map of Mwani Crater, Sultan Hamud.

The lower olivine basalt outcrops in the Kwawatingila River a little to the north of Sultan Hamud and is overlain by a coarse agglomerate containing irregular blocks, measuring up to 3 ft. in diameter, of olivine basalt and Basement System gneisses and amphibolites. Small scoracious lava blocks and light-coloured ash containing olivine and augite crystals fill the interstices between the larger boulders. Higher in the succession a fine-grained pyroclastic series free from Basement System gneisses and comprising grey volcanic breccias with small boulders and angular fragments of olivine basalt dips outwards from near the rim of the crater. The lower portions of the crater wall are occupied by inwardly-dipping olivine basalt cone-sheets. Above them and occupying part of the floor of the crater is a brownish-red incoherent ash containing small pellets and scoracious and ropy fragments of lava. The latest eruption is represented by 6 ft. of olivine-basalt surmounting the ash at Mwani South.

The lower lavas (specimens 59/43, 59/90, 59/91 and 59/150) are black vesicular rocks with phenocrysts of olivine up to 5 mm. in length, and streaks of white zeolitic material. Thin sections show colourless or pale green phenocrysts of euhedral olivine partly replaced by serpentine, iddingsite or bowlingite. Phenocrysts of augite, which are often titaniferous, are rare, this mineral usually being confined to the groundmass where, together with magnetite and a little interstitial plagioclase, it forms a fine-grained granular mosaic. Magnetite occurs both as phenocrysts, often the same size as the olivines, and as a second generation in the groundmass. Plagioclase feldspar is rare, but when present is confined to the groundmass in plates attaining a length of 1 mm. and with micropoikilitic texture (specimen 59/43).

The middle lavas (specimen 59/45) around the crater rim are more compact and less vesicular than the lower lavas. Again olivine and magnetite are phenocrystic, the latter also being prominent in the groundmass which consists of a densely packed aggregate of magnetite, titan-augite and plagioclase. A little lepidomelane, closely associated with magnetite, is present.

The upper lavas of Mwani differ from those lower in the succession in being finer-grained and in showing flow banding. Olivine, augite and magnetite again occur as phenocrysts.

The agglomerate boulders consist of previously consolidated olivine basalt which solidified in the volcanic vent pending expulsion during the next explosive phase. A thin section of the lower breccia shows much Basement System material including hornblende, garnet, epidote, quartz, microcline, oligoclase and apatite together with fragments of olivine, augite, magnetite and perovskite.

The Mwani sequence is roughly repeated in the other major volcanoes where there are thick broad expanses of agglomerate containing boulders of olivine basalt, with intercalated grey breccia and ash, and occasional lava flows. The upper third of the volcanoes consists of coarsely bedded brownish-red volcanic ash and breccia, often containing peculiarly-shaped, highly-scoracious blocks of lava, some resembling a coiled serpent, others a Swiss-roll. Excellent exposures of ash are seen at Selengai and along the road to the south-east. This ash is a dark grey irregularly bedded rock with alternating fine and coarse bands, each individual grain being joined to its neighbour by a calcareous cement. All the lavas are olivine basalts and contain olivine in various stages of alteration. A high iron ore content, noticeable in thin section and by the abundance of hematite and limonitic staining around the volcanic vents, is a characteristic feature.

The ropy, vericular blocks of lava found at the summits of the larger volcanoes differ in appearance and grain size from the lavas lower in the succession. Fresh surfaces show hues of purplish-brown in which may be seen small green crystals of olivine and occasional black augites.

Dyke rocks are predominantly holocrystalline and vesicular in the centre of the intrusion becoming almost tachylitic and less vesicular towards the edge. They consist of approximately 45 per cent augite, 25 per cent plagioclase, 20 per cent olivine and 10 per cent magnetite. Olivine occurs as semi-rounded phenocrysts showing partial alteration to serpentine and bowlingite. Augite is occasionally present as phenocrysts, but together with magnetite and a micropoikilitic plagioclase forms the major part of the groundmass. Stilbite, calcite and natrolite have crystallized in the vesicles.

VI—RECENT SEDIMENTS

Recent deposits in the area are associated with fluvial deposition and with peneplanation. Pale-brownish loess-like soil forms the 4,000-ft. terrace of the Mkuyu River between it and Mooni, but the soil turns reddish-brown on approaching lava outcrops. Similar brown soils form low bluffs along the upper reaches of the Selengai and Bissel Rivers.

Areas of internal drainage, of which there are many, consist mainly of thick black cotton soils, some containing an admixture of alluvium. These basins of deposition are shown on the map. The soils have accumulated by the sheet-flow and seepage of water from neighbouring areas, where the gradient is not sufficiently steep for gulying or stream flow to take place, into areas of slightly lower relief where the water, becoming stagnant, allows bacterial decomposition of the vegetation, giving rise to black cotton soils.

In times of flood the Selengai, Bissel and other smaller rivers deposit their loads at a flattening of the gradient, where the reduced rate of flow diminishes their capacity. Large expanses of flood plain are thus built up at each flood tide and consist of very fine-grained grey sandy soils and alluvium which, below the point where the Selengai River aggrades, become mixed with black cotton soil. These particular soils allow the growth of scattered acacia trees, taller than usual in the area, and coarse, wiry grass.

Typical penepplain soil exists on the Basement System terrain and comprises a varied admixture of coarse to fine-grained grit and sand containing angular fragments of quartz and felspar. Locally the sands are rich in magnetite, garnet, hornblende or epidote derived from nearby sources. Samples of sands from various sand-rivers were collected and a study of their heavy minerals revealed the following species:—

<i>Abundant</i>	<i>Common</i>	<i>Rare</i>
Garnet.	Diopside.	Hypersthene.
Magnetite.	Epidote.	Rutile.
Ilmenite.	Apatite.	Kyanite.
Hornblende.		Zircon.

Reddish-brown iron-rich soils are derived from the volcanic rocks but owing to their recent age little weathering has taken place and very little soil has been formed, the largest expanse lying along the road south-east from Emali. Magnetite, olivine and augite are typical of the sands that arise from the weathering of the volcanic rocks.

VII—STRUCTURE

Three distinct structural units were recognized in the area: (1) a block with north-easterly dips in the south-west; (2) a concentric "swirl" structure with a focal point of granite in the north, and (3) large "elbow" folds lying outside the concentric zone (Fig. 7).

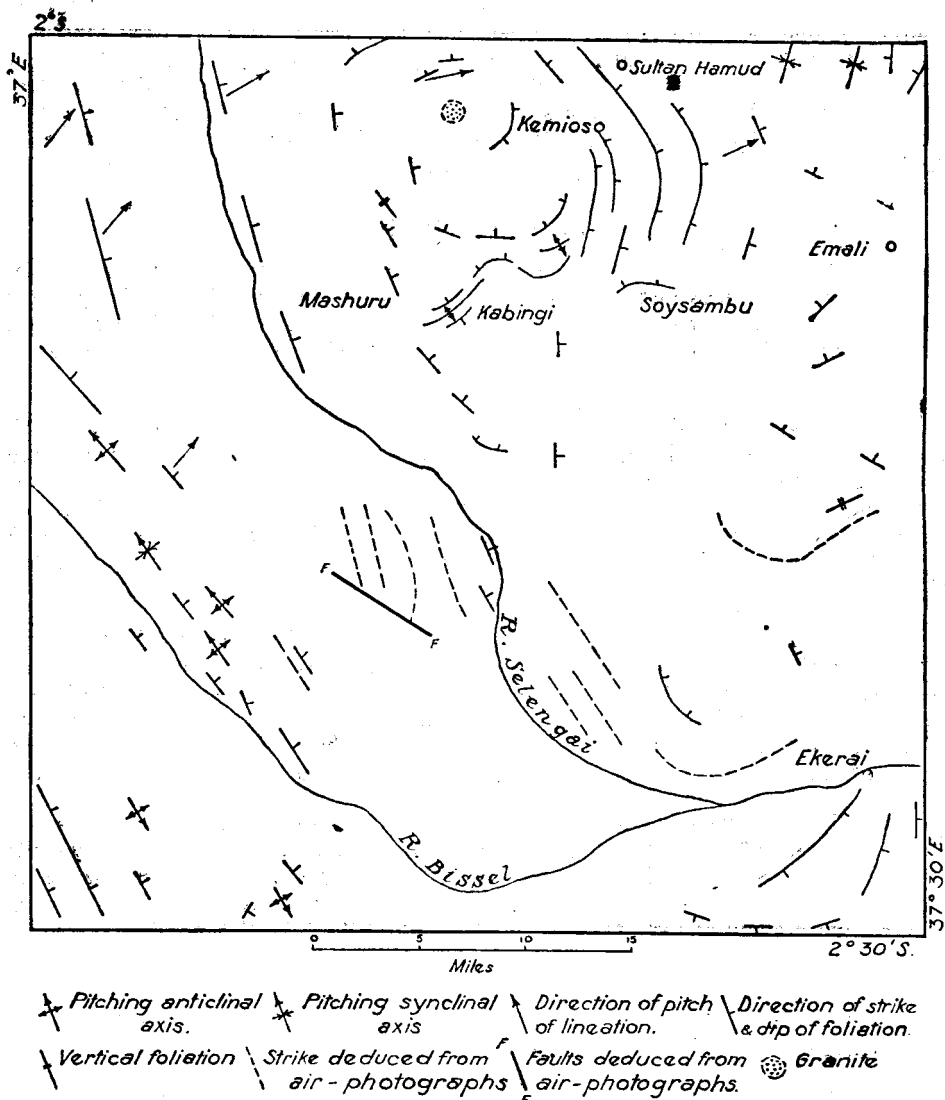


Fig. 7.—Structural map of the Basement System rocks in the Sultan Hamud area.

A thick outcrop of marble striking N.W.-S.E. and dipping at 20° to the north-east forms the Ngarigaishi hills in the south-west corner of the area. Outcrops are few away from the hills but up to the Bissel River a series of anticlines and synclines is a prominent feature, those in the south pitching south-east and those in the north to north-west. Lineation was not observed in this part of the area, but it is considered that it probably follows closely the strike of foliation. North of the Bissel River in the north-west corner of the area the strike of foliation swings to N.N.W.-S.S.E. The lineation here pitches north-east, but becomes more easterly towards Sultan Hamud. A fault-line extending for over two miles near the centre of the area separates the two areas of different strike and lineation directions and emphasizes the tectonic difference between the north-eastern and south-western portions of the area.

The concentric structure is a most distinctive feature. It is one of a series of such structures that occupy the ground from Sultan Hamud northwards to Machakos and beyond. They are better developed in the Machakos area where a central core of granitoid gneiss with concentric foliation is surrounded by concentric folds in the surrounding metamorphic rocks. The structures wrap around the central core and perhaps the series of centres can be best visualized by likening them to whirlpools which develop *en échelon* in a fast-flowing stream. The structure south-west of Sultan Hamud consists partly of inwardly- and partly of outwardly-dipping strata, with a focal point coinciding with an outcrop of granite. This small outcrop occurs at the summit of a broad rounded hill and could not be traced for any great distance. The nearest exposures to the granite, however, consist of granitoid gneiss. An outwardly dipping arcuate ridge consisting of muscovite gneiss, muscovite quartzite and muscovite-kyanite quartzite occurs $3\frac{1}{2}$ miles east of the granite on the same horizon as a muscovite gneiss in the Machakos District. A theory of the origin of this structure can be only tentatively suggested from evidence obtained in the present area. It is considered that a centre of intense granitization, now represented by granite and granitoid gneisses, became sufficiently plastic to allow east-west compressional forces to cause a rotation of the surrounding rocks around a central vertical axis, the sense of rotation being considered as anti-clockwise. Two distinct blocks of metamorphic rocks appear to have existed, a south-west block where granitization centres did not develop and a north-east block in which considerable movement took place around softened centres. The shearing effect produced by the movements in the north-east block may have been responsible for the minor N.W.-S.E. folding in the south-east block. The production of tear-faults between blocks of differing resistance as a result of the rotational movements would be expected. The focal point of the "swirls" would act as channels for the introduction of later metasomatizing fluids, leading to the formation of fronts around them in which potash metasomatism was more intense than in the remainder of the area, and which became fixed in the quartzite at Kemioso and in the numerous muscovite pegmatites that extend in an arc from west of Sultan Hamud through Kamap, Kasabe and Ususu to the foothills of Kiasa. Rocks close to the centre of the structure would suffer the most intense metasomatism, ultimately giving rise to granitoid gneisses and granite.

The large "elbow" folds around Ekerai are considered to be associated with the compressional movements. Exposures are poor and several of the structures have been deduced from aerial photographs.

An example of flow-lining of a transverse fracture (Fig. 2E) was noted in the Selengai River, half a mile south of Mashuru dukas. The shear-zone is occupied by vertically foliated biotite gneiss, containing lenses and streaks of pegmatite, and with sharp contacts against the normally foliated host-rock. It is interesting to note that pegmatites and small fracture zones in the upper reaches of the Selengai River trend between 40° and 80° east of north, which corresponds to the direction of lineation and is perpendicular to the presumed direction of compression.

VIII—ECONOMIC GEOLOGY

1. General

No minerals of economic importance are being produced from the area at present although in the past a small quantity of mica was mined. *Beryl* was discovered in small amounts in some of the mica-bearing pegmatites but as mica mining has been suspended none has been found in recent years. *Tourmaline* and *garnet* are often associated with the mica-bearing pegmatites but are of no economic significance. A *graphite-schist* was

noted outcropping in an isolated part of the area south of Mutoroki bore-hole No. 2. Its traceable extent was only a few yards and, even if it were larger, the absence of water combined with distance from a motorable road make any exploitation of the deposit unlikely. No significant trace of *gold* was discovered though several quartz-rocks were assayed by the Government Chemist and Assayer, the results being as follows:—

<i>Spec. No.</i>	<i>Dwt. gold/ton</i>	<i>Locality</i>
59/125	0.6	Shear-zone at southern end of Ngarigaishi hills.
59/194	0.1	Vein on N. side of Kanamou Kidogo.
59/196	trace	4½ miles N.W. Ususu.
59/220	0.1	1½ miles E.N.E. of Musuriamboi.

Brittle *asbestiform fibre* associated with *talc-schist* outcrops on the southern end of a spur three-quarters of a mile north of Mutini hill. Two trenches were dug but no further fibrous material was found. There is no economic importance in either this or a second outcrop, 1½ miles west-north-west of Mutini.

2. Kyanite

Kyanite has been found in schists and gneisses in scattered parts of the area but in only one instance did it show signs of being present in large quantities. The deposit outcrops on the northern flank of a knoll 3½ miles south-east of Musuriamboi. It dips north-east at 20° and measures 80 yards in length and 40 yards in width, though these figures take no account of possible concealed extensions lying beneath a covering of red sandy soil. Three hand-specimens were tested by heavy liquid separation, using potassium mercuric iodide. The products were examined under a microscope and in each case the "heavies" were found to consist almost entirely of kyanite with a little rutile and ilmenite whilst the light fraction consisted chiefly of quartz with some muscovite and up to 5 per cent kyanite. The "heavies" were mixed and assayed with the following result:—

		<i>Heavies</i>		<i>Lights</i>		<i>Analysis of Heavies</i>			
		<i>Per cent by weight</i>							<i>%</i>
59/219 (A)	..	80	..	20	..	Al ₂ O ₃	..	..	58.16
59/216 (B)	..	71	..	29	..	Fe ₂ O ₃	..	..	0.79
59/47 (C)	..	37	..	63	..	TiO ₂	..	..	1.53

These figures were encouraging and a Government prospector was sent to pit and trench the deposit. Extensive excavation was carried out, including a shaft that passed through the horizon, and calculations by P. Joubert indicate that there is 500,000 tons of kyaniferous rock available, containing an average of only 14.5 per cent of kyanite. The trenching indicated that numerous bands of non-kyaniferous rock that do not outcrop are present, and considerably dilute the tenor of the horizon as a whole. The highest result obtained in the shaft, which intersected 32 ft. of kyanite schists, was 26.8 per cent of kyanite over a thickness of 5 ft.

A muscovite-kyanite-quartz schist forms part of the small hogs-back ridge of Kemioso, situated five miles south-west of Sultan Hamud. The principal components of

the schist are quartz and muscovite with, in places, colourless blades of kyanite. A mineral count gave the following volume percentages for the kyanite-bearing varieties:—

59/26			%
Quartz	..	..	50.7
Muscovite	..	..	39.3
Kyanite	..	..	9.3
Rutile	..	..	0.7

The percentage of kyanite is not great and the deposit has no economic possibilities.

3. Mica

Interest in mica was first shown in 1939 when P. H. Cull discovered workable deposits south of Sultan Hamud Station. Small quarries were subsequently opened up on Karibani hill, Kamumu, Ususu, Emali Tatu hill and at Kwangi I and Kwangi II. A considerable amount of ruby mica and green mica was extracted during the early part of the 1939–45 war but no records of production are available.

Although some of the quarries attain a depth of up to 30 ft. the mica-bearing pegmatites are by no means exhausted but increasing overburden will have a depreciating effect in some of the quarries, notably at Ususu and Karibani. In others, such as at Kwangi I and Kwangi II, there is every probability that the pegmatites can be traced laterally along their strike. A considerable amount of coarse-grained muscovite gneiss and muscovite pegmatite occurs on the small knoll immediately west and north-west of Kiasa and this area appears promising for mica prospecting.

4. Limestone

(1) Introduction

Considerable interest has been shown recently in the deposits of magnesia-poor crystalline limestone that are situated south of Sultan Hamud Station in the Masai district. These deposits, originally prospected by Mr. P. H. Cull, were later regarded as being of economic value and a company was floated in 1949 called Industrial Cements, Limited. The company went into liquidation in 1951 before any plant had been erected or any development undertaken.*

In 1949, when interest was first aroused in the limestones as a possible source of material for cement manufacture, Dr. B. N. Temperley† paid a visit to the area and produced a report on its potentialities. He also assessed the water supply of the area, the possibilities of utilizing local clays in cement manufacture and sited bore-holes both for water and for the exploration of the limestone at Kabingi hill and Mutini hill.

(2) Occurrence

Crystalline limestone outcrops are fairly widespread in the neighbourhood of Sultan Hamud, the principal localities being as follows: Kabingi, Mutini N.W., Mutini S.E., No. 1 Limestone, No. 2 Limestone, No. 3 Limestone, No. 4 Limestone and No. 5 Limestone. All these limestones occur within five miles of the Kabingi Limestone, though other even larger deposits occur at Leme Boti and in the Ngarigaishi hills.

(3) The Kabingi Limestone

This limestone, situated 10 miles south-west of Sultan Hamud, is connected by a lorry track to the Nairobi–Mombasa road. Four outcrops are recognized in the main

* Early in 1953 the East African Portland Cement Co., Ltd., acquired rights to work the limestones. In conjunction with European interests an extensive programme of exploration is being carried out, with a view to erecting a factory capable of producing 100,000 tons of cement per year.

† The technical advisers of the East African Portland Cement Co., Ltd., are unable to agree with all the conclusions arrived at by Dr. Temperley, and particularly with his computations of the amounts of limestone available.

area and are represented respectively as P, Q, R and S in Fig. 8. Two other small lenticular outcrops occur further up the hill to the north-west. Beds P, Q and R outcrop on the sloping end of a south-easterly facing spur whilst bed S underlies flatter ground at the base. Beds P and R measure 600 yards along their visible strike which runs N.E.-S.W., whilst Q extends only 400 yards from the southern end of the outcrops where they are covered by volcanic ash before tapering out. Outcrop S is triangular in shape with its apex to the south-west and disappears 200 yards to the north-east under a bed of volcanic ash.

Most of the limestone bands appear to dip steeply to the south-east passing under the bed S, which represents the centre of a synclinal fold the axis of which pitches north-east. The northern part of bed P probably dips to the north-west as a whole and represents overturns in that limb of the fold. The contiguous rocks are predominantly biotite gneisses and schists which are not conspicuous at the surface but are indicated by the superficial occurrence of their constituent minerals.

The outcrops of beds P, Q and R are interrupted by a fault, which has been considered as a low-angled thrust-plane part of which is occupied by biotite gneiss with strike parallel to the length of the fault. It is possible that its foliation resulted from the shearing of the northernmost beds over their southern counterpart with a consequent readjustment of the gneissic minerals during granitization.

In his first report Dr. Temperley recommended and sited six bore-holes, five of which were to be inclined and one vertical. Of these only two were drilled at the places recommended but three others (Nos. 3a, 7 and 8) were drilled which were not recommended in the report. The position of these drill-holes is shown on Fig. 8. In bore-hole No. 2 three limestone beds corresponding to those at the surface were intersected, though bed R thins underground. In bore-hole No. 8 four limestone bands were encountered at depth though only two are exposed at the surface. The first limestone band corresponds to R and the second to Q which wedges out before reaching the surface. Bed P splits into two portions at depth with an intervening wedge of schist. There is no surface indication of the interfingering and intercalation of the limestone and schist which was so commonly experienced in the bore-hole cores. This feature is emphasized in bore-holes Nos. 3 and 3a, both of which lie in the same plane but inclined at different angles. Here limestone R must wedge out at approximately 100 ft. into schist, since bore-hole No. 3 did not reach limestone before 160 ft. The possibility of a reversed strike-fault accounting for the non-occurrence of the bed cannot be overlooked.

A cavity was found to exist for a distance of 70 ft. at the end of bore-hole No. 2. Its nature is not known; it may be a solution hollow in the limestone or a narrow fissure coinciding with a joint-plane.

Bore-hole No. 7 is situated very close to the axis of the syncline and shows two principal limestone bands, the upper being 114 ft. and the lower 56 ft. thick, separated by 30 ft. of schist.

The direction of dip of the strata in the bore-holes is not accurately known, which makes it impossible to correlate limestone beds at depth with those on the surface with absolute certainty. The planes of schistosity cut the cores at angles varying from 50° to 90° but one cannot determine whether the beds are dipping steeply or not, though in any case the error in tonnage estimation would not be great. It is possible that minor folding or puckering of the beds has taken place.

(a) *Tonnages.*—In calculating the quantities of limestone available beds of 3 ft. thickness or less, isolated by more than 3 ft. of schist, were neglected. Thicker beds were counted and where separated by beds of schist less than 3 ft. thick they were grouped together and considered as a single bed with a percentage of intercalated schist. In this

way the limestones were found to vary in thickness from 7 ft. to 60 ft. with an average of 30 ft., whereas the schist intercalations varied from nil to 33 per cent with an average of 7 per cent. In converting the volumes to weight a cubic yard of limestone was taken as weighing 2 tons (or 165 lb. per cubic foot). The following tonnages of limestone were deduced to be available between the surface and a depth of 300 ft.

Limestone	Tonnage (millions of tons)	Limestone/schist ratio
P, Q, R	6.5	1:1.45 to 1:0.88
S	1.3	1:0.25
Total ..	7.8	

(b) *Lateral Extensions.*—There is every indication that limestones P, Q and R extend north-eastwards under the ash cover for about 100 yards, but decrease in thickness. They likewise extend to the south-east, again under an ash covering, but to what distance is not known. The limestone S probably widens and deepens north-eastwards but the reserves of rock economically available are correspondingly diminished by a lowering of the surface and a thicker ash overburden. Allowing a 100-yard extension of the limestone beds P, Q, R and S under the volcanic ash a further 2.5 million tons is anticipated, giving a total of 10.3 million tons. It must be remembered that at the extremities of these limestones, the overlying volcanic ash is about 50 ft. thick and any further extension of quarrying would be uneconomical.

(c) *Composition of the Limestone.*—Limestones were sampled in four bore-holes (Nos. 2, 3a, 7 and 8) and the samples analysed for CaO, MgO and loss on ignition by the East African Industrial Research Board (Table II).

(4) *The Mutini N.W. Limestone*

A plan and section of the Mutini deposit are given in Fig. 9 (at end). The principal outcrop lies in a col across the spur behind Mr. Cull's house. A pit approximately 9 ft. square has been sunk to a depth of 14 ft. and shows a coarse white marble, with occasional light and dark bands, having an almost E.-W. strike and a westerly dip of 23°. This limestone can be traced north-eastwards down the flank of the hill where it disappears beneath alluvial soil; it does not outcrop again on the other side of the valley. Like the Kabingi limestone it is associated with bands of schist. The outcrop below the col on the north-east side is broken by a cross-cutting pegmatite, which may represent the line of a fault according to Dr. Temperley. Three limestone beds occur to the south-west of this pegmatite, the upper and middle beds consisting of coarse-grained crystalline limestone and the lower of fine-grained limestone.

The thickness of the group of limestones varies along the strike from 5 ft. to 22 ft., whilst the intervening schist bands range from 5 ft. to 15 ft. in thickness. The ratio of overburden to limestone is high. For the extraction of 1,000,000 tons of limestone an equal amount of schist would have to be removed. With further excavation of limestone an even greater proportion of schist would have to be removed.

Other limestones, which lie stratigraphically below the above-mentioned limestones, occur immediately west of the col and can be traced at intervals along the contour to the south and thence in an arc to the next spur to the south-west. The lower bed, about 6 ft. in thickness, dips into the hills it flanks and represents part of an anticlinal fold, the axis of which trends W.N.W. and passes through Mutini hill.

Dr. Temperley concluded that these limestone would not be an economic proposition owing to the high ratio of overburden to limestone, and consequently no bore-holes were drilled.

(5) *Mutini S.W. Limestone*

A further bed of limestone cuts obliquely across two ridges trending N.E. and S.E. respectively, from the summit of Mutini hill. The outcrop is 600 yards long, about 20 feet thick, and trends N.-S. with a dip to the east of 45°. No particular attention has been paid to this limestone though there is no reason why its composition should differ much from that of the Mutini N.W. Limestone.

(6) *No. 1 Limestone*

No. 1 Limestone is situated about 3½ miles south-east of the Kabingi Limestone and outcrops on a low rise surrounded by red earth. The outcrop measures 350 yards in length, with a north-south strike and a dip of 55° E. Although no schist is exposed crystals of black kyanite are scattered abundantly on the surface.

(7) *No. 2 Limestone*

No. 2 Limestone outcrops on a low ridge about 4½ miles S.S.E. of Kabingi. It has a high MgCO_3 content.

(8) *No. 3 Limestone*

No. 3 Limestone is exposed on a rise in the flat country about 3½ miles south of Kabingi and is partly covered by a skin of kunkar limestone. The strike length is 400 yards whilst the exposed width measures 200 yards. The strike swings from E.-W. at its eastern end to N.W.-S.E. at its western end. It is estimated by Dr. Temperley that the quantity of limestone available to a depth of 300 feet is about 12,000,000 tons.

(9) *No. 4 Limestone*

No. 4 Limestone is a small outcrop situated about five miles east of Kabingi. It has not been surveyed since its position and composition are not favourable.

(10) *No. 5 Limestone*

No. 5 Limestone occurs on a small rise 1½ miles S.W. of Kabingi. The exposures are poor though sufficient to show a N.E.-S.W. strike and a south-easterly dip of about 40°, the outcrop being 150 yards in length and 80 yards in width. Assuming the workable length of the occurrence to be 350 yards and the width of limestone without schist bands as 40 yards, it is estimated that 3,000,000 tons of ore exist down to a depth of 300 feet.

The total amount of quarriable limestone available at localities 1, 3 and 5 is regarded as being 23,000,000 tons.

5. Water Supply

For his early report (1949) on the limestones at Kabingi, Dr. Temperley consulted the Public Works Department with regard to the water supply at Sultan Hamud. It was considered that the chance of obtaining a large permanent supply from a reservoir in the country around Sultan Hamud was slight and that consequently the only possible sources of water were bore-holes. It was later suggested that a dam should be built about one mile south-west of Sultan Hamud Station to flood part of the area drained by the Errui River. The amount of water carried by this relatively small river fluctuates considerably, sometimes with disastrous results such as were experienced in May, 1951, when the railway embankment at the approach to Sultan Hamud Station was washed away and the water reached to within a few inches of the top of the rails.

Seven bore-holes have been drilled at Sultan Hamud (*see* Table III) all of which have yielded abundant supplies of good quality water but, owing to the nature of the

TABLE II.—CHEMICAL COMPOSITION OF THE KABINGI LIMESTONES

POSITION OF SAMPLE			ANALYTICAL DATA			INGREDIENTS BY RECALCULATION		
Borehole No.	Limestone horizon	Depth from surface in feet	per cent CaO	per cent MgO	per cent loss on ignition	per cent CaO as CaCO ₃	per cent MgO as MgCO ₃	Other ingredients by difference
8	Bed R top	49	54.69	0.13	42.70	97.66	0.27	2.07
	bottom	202	54.48	0.21	42.51	97.29	0.44	2.27
	Q middle	265	52.70	0.17	41.08	94.11	0.36	5.53
	P2 top	342	55.63	0.20	42.76	99.31	0.42	0.27
2	P1 bottom	457	49.88	0.26	42.15	89.07	0.54	10.39
	R bottom	100	55.70	0.07	43.18	99.17	0.15	0.68
	P top	220	54.65	0.30	42.27	97.59	0.63	1.78
	R1 bottom	193	54.08	0.10	42.10	96.57	0.21	3.22
3	Q bottom	260	50.79	0.18	43.74	90.70	0.38	3.92
	P bottom	378	53.48	0.34	41.52	95.50	0.71	3.79
7	S1 bottom	140	55.82	0.14	43.07	99.68	0.29	0.03
	S2 bottom	214	53.76	0.20	42.28	96.00	0.42	3.15
Averages	.. ..	..	53.81	0.19	42.45	96.05	0.40	3.54

N.B.—Beds P1 and P2, etc., are subdivisions of Bed P, etc., where split by schists.

TABLE III.—BORE-HOLES IN THE SULTAN HAMUD AREA

Bore-hole Number	Name	Depth in feet	Depth at which water was struck	Height to which water rises	Yield (gal./24 hrs.)
C3 ..	Sultan Hamud ..	312	169	50	86,400
C51 ..	Sultan Hamud ..	300	127 190	109	480 1,728
C55 ..	Sultan Hamud ..	400	122	104	960
C111 ..	Sultan Hamud ..	183	162	158	68,000
C315 ..	Sultan Hamud ..	195	165	156	36,000
C359 ..	Sultan Hamud ..	193	165	150	48,000
C552 ..	Sultan Hamud ..	400	298 380	307	60,000
C975 ..	Mashuru ..	450	212	125	27,600
C1136 ..	Ekerai ..	301	260	93	57,600
C1151 ..	Emugurr ..	344	300	110	72,000
C1183 ..	Olosingoram ..	400	125	74	19,200
C1231 ..	Mutoroki No. 1	350	134	120	21,600
C1290 ..	Mutoroki No. 2	316	127	120	48,600
C1221 ..	Lengesim ..	253	230	64	51,800

sub-surface rocks, they have a tendency to become silted up. Most of the bore-holes have been sunk in the vicinity of the railway station. The minimum depth to which it was necessary to sink in order to reach the contact of the volcanic rocks with the underlying gneisses and schists was 120 ft., and the maximum so far recorded is 190 ft., when the water-table was reached at a depth of 165 ft. in the basal volcanic series.

A reliable drill-log was recorded by the Army when drilling bore-hole No. C.315. Fifteen feet of black cotton clay was underlain by 60 ft. of olivine basalt, followed by 50 ft. of ash and lava fragments. Xenoliths of Basement System rock together with volcanic ash were next encountered for a depth of 30 ft. passing finally into a sandy soil derived from weathered gneisses. There seems little doubt from bore-hole records that an old land-surface lies at about 108 to 130 ft. below the present surface and another at about 170 ft., the latter representing the pre-volcanic land surface. Both these horizons are aquifers though a bigger yield is obtained at the lower level.

Since a better water supply is obtained from the sub-Pleistocene surface at the base of the volcanic rocks than from the gneisses and schists themselves, a suitable area for obtaining water lies to the south-west of Sultan Hamud Station between Karibani and Kwangi I, and between these points and Kemioso close to the Errui River. A similar result can be expected from Sultan Hamud along the railway to beyond Emali and likewise to the south of Emali for a distance of up to four miles.

There appears to be no reliable expectancy with regard to the depth of the water-table elsewhere in the area. Water has collected at levels varying from 127 ft. to 300 ft. below surface. On the whole water may be expected between these depths at any point in the area south of the Mashuru-Laitokitok road. There is no justification whatsoever in sinking bore-holes well out in black cotton soil areas such as at Mutoroki No. 1 and to a lesser extent at Lengesim. The results of flooding upon the weak foundations of the pump house and the water tank might prove disastrous. There is no reason at all why

water should not be found by drilling on the edge of the black cotton areas where the surface rocks are weathered Basement gneisses and are not liable to floods. The difference in surface level is less than 6 ft. and structures and rock types exposed off the black cotton areas are the same as those underneath them.

6. Clays

A representative of Industrial Cements, Limited, sampled the red soil between Mr. Cull's house and the base of Mutini Hill and pronounced it satisfactory to mix with the limestone in the manufacture of cement. Similar red soil covers the lower slopes of all the Basement System hills in the neighbourhood. Black clays are abundant in more low-lying ground though they do not contain gypsum as has been noted at Konza.

7. Building Material and Road Metal

The lavas in the vicinity of Sultan Hamud would be suitable for road metalling though quarrying would have to be undertaken in large vertical pits which would be susceptible to flooding in wet weather. A better prospect is the Kapiti phonolite from Athi River or the basalt at Kibwezi. The incoherent nature of the volcanic ashes and breccias prohibits their use as building material.

IX—LOG OF BORE-HOLES

The position of the diamond drill-holes sunk at Kabingi is shown in Fig. 8. Nos. 2, 3, 3a and 8 are inclined whilst No. 7 is vertical.

BORE-HOLE NO. 2

DEPTH		
From	To	
<i>ft. in.</i>	<i>ft. in.</i>	
0 0	34 0	No core.
34 0	36 0	Gneiss.
36 0	111 0	Crystalline limestone.
111 0	112 0	Gneiss.
112 0	115 0	Crystalline limestone.
115 0	118 0	Gneiss.
118 0	118 6	Crystalline limestone.
118 6	158 0	Gneiss.
158 0	186 0	Crystalline limestone.
186 0	191 0	Gneiss.
191 0	191 6	Crystalline limestone.
191 6	195 0	Gneiss.
195 0	200 0	Crystalline limestone.
200 0	215 0	Gneiss.
215 0	220 0	Crystalline limestone.
220 0	222 0	Gneiss.
222 0	229 0	Crystalline limestone.
229 0	231 0	Gneiss.
231 0	236 0	Crystalline limestone.
236 0	240 0	Gneiss.
240 0	247 0	Crystalline limestone.
247 0	251 0	Gneiss.
251 0	253 0	Crystalline limestone.
253 0	265 0	Gneiss.
		<i>Bottom of bore-hole</i>

BORE-HOLE No. 3

DEPTH				
From		To		
<i>ft.</i>	<i>in.</i>	<i>ft.</i>	<i>in.</i>	
0	0	164	0	Gneiss.
164	0	194	0	Crystalline limestone.
194	0	217	0	Gneiss.
217	0	218	6	Crystalline limestone.
218	6	220	0	Gneiss.
220	0	239	0	Crystalline limestone.
239	0	240	0	Gneiss.
240	0	257	6	Crystalline limestone.
257	6	258	6	Gneiss.
258	6	280	0	Crystalline limestone.
280	0	282	0	Gneiss.
282	0	287	0	Crystalline limestone.
287	0	289	0	Gneiss.
289	0	312	0	Crystalline limestone.
312	0	313	0	Gneiss.
313	0	318	0	Crystalline limestone.
318	0	319	0	Gneiss.
319	0	330	0	Crystalline limestone.
330	0	331	0	Gneiss.
331	0	340	0	Crystalline limestone.
340	0	343	0	Gneiss.
343	0	346	0	Crystalline limestone.
346	0	351	0	Gneiss.
351	0	357	0	Crystalline limestone.
357	0	361	0	Gneiss.
361	0	379	0	Crystalline limestone.

Bottom of bore-hole

BORE-HOLE No. 3A

0	0	27	0	Gneiss.
27	0	51	0	Crystalline limestone.
51	0	55	0	Gneiss.
55	0	58	6	Crystalline limestone.
58	6	60	0	Gneiss.
60	0	75	0	Crystalline limestone.
75	0	96	0	Gneiss.
96	0	110	0	Crystalline limestone.
110	0	111	0	Gneiss.
111	0	116	0	Crystalline limestone.
116	0	117	0	Gneiss.
117	0	130	0	Crystalline limestone.
130	0	136	6	Gneiss.
136	6	138	0	Crystalline limestone.
138	0	141	0	Gneiss.
141	0	148	0	Crystalline limestone.
148	0	162	0	Gneiss.
162	0	163	6	Crystalline limestone.
163	6	165	0	Gneiss.
165	0	166	6	Crystalline limestone.
166	6	170	0	Gneiss.
170	0	181	0	Crystalline limestone.
181	0	182	0	Gneiss.

BORE-HOLE No. 3A—(Contd.)

DEPTH				
From		To		
ft.	in.	ft.	in.	
182	0	184	0	Crystalline limestone.
184	0	194	0	Gneiss.
194	0	216	0	Crystalline limestone.
216	0	226	0	Gneiss.
226	0	237	0	Crystalline limestone.
237	0	238	6	Gneiss.
238	6	242	0	Crystalline limestone.
242	0	243	0	Gneiss.
243	0	276	0	Crystalline limestone.
276	0	279	0	Gneiss.
279	0	304	0	Crystalline limestone.
304	0	318	0	Gneiss.

Bottom of bore-hole

BORE-HOLE No. 7

0	0	11	0	Soil.
11	0	37	0	Crystalline limestone.
37	0	38	0	Gneiss.
38	0	67	0	Crystalline limestone.
67	0	69	0	Gneiss.
69	0	73	0	Crystalline limestone.
73	0	78	0	Gneiss.
78	0	97	0	Crystalline limestone.
97	0	99	6	Gneiss.
99	6	100	6	Crystalline limestone.
100	6	102	6	Gneiss.
102	6	108	6	Crystalline limestone.
108	6	110	0	Gneiss.
110	0	124	0	Crystalline limestone.
124	0	154	0	Gneiss.
154	0	192	0	Crystalline limestone.
192	0	195	6	Gneiss.
195	6	212	0	Crystalline limestone.

Bottom of bore-hole

BORE-HOLE No. 8

0	0	49	0	Gneiss.
49	0	122	0	Crystalline limestone.
122	0	123	0	Gneiss.
123	0	130	0	Crystalline limestone.
130	0	131	6	Gneiss.
131	6	197	6	Crystalline limestone.
197	6	234	0	Gneiss.
234	0	237	0	Crystalline limestone.
237	0	244	0	Gneiss.
244	0	252	0	Crystalline limestone.
252	0	253	0	Gneiss.
253	0	255	0	Crystalline limestone.
255	0	256	0	Gneiss.
256	0	266	0	Crystalline limestone.
266	0	267	0	Gneiss.

BORE-HOLE No. 8—(Contd.)

DEPTH				
From		To		
ft.	in.	ft.	in.	
267	0	271	0	Crystalline limestone.
271	0	338	0	Gneiss.
338	0	342	0	Crystalline limestone.
342	0	347	0	Gneiss.
347	0	351	0	Crystalline limestone.
351	0	352	0	Gneiss.
352	0	369	0	Crystalline limestone.
369	0	370	0	Gneiss.
370	0	377	6	Crystalline limestone.
377	6	412	0	Gneiss.
412	0	415	0	Crystalline limestone.
415	0	425	0	Gneiss.
425	0	454	0	Crystalline limestone.
454	0	464	0	Gneiss.
				<i>Bottom of bore-hole</i>

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