Report No. 46

COLONY AND PROTECTORATE OF KENYA

MINISTRY OF COMMERCE AND INDUSTRY
GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
MID-GALANA AREA

DEGREE SHEET 66, NW. QUARTER
(with coloured map)

by

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FOREWORD

The publication of the report on the geology of the Mid-Galana area, an area about half-way between Malindi and Tsavo, completes the presentation of official geological mapping carried out in the southern part of the coastal belt of Kenya, south of the third south parallel and east of longitude 38° E., since the end of 1949. In it Mr. Sanders continues the story of the relationship of the Karroo beds of coastal Kenya to the ancient rocks that lie further inland. Further south, in the Mariakani–Mackinnon Road area (Report No. 20), the boundary is everywhere faulted, but in the Mid-Galana area it is in part faulted and in part an unconformable junction.

Mr. Sanders has carefully examined the lowest of the beds so exposed and considers that they include a tillite that was deposited during the time of the lower Karroo Dwyka glaciation. He has also shown that fossils recovered many years ago from what was supposed to be the lower beds of the sequence come, in fact, from a higher part. These discoveries indicate that there is a full succession of Karroo beds in this area and that the base is not in the Beaufort as had previously been thought in adjacent areas. It is in the lower parts of the Karroo that the coal seams of southern Africa and Madagascar occur. In the Mid-Galana area only coalified plant remains have been found in the exposed beds that are considered of equivalent age. In view of the faulting over much of the junction of the old rocks and the Karroo, however, it is believed that more complete sequences of the lower beds may be concealed in basins that nowhere come to surface. Their discovery will depend on geophysical work and drilling and, even if found, there is no guarantee that the expanded sequences will contain coal seams. Such basins, however, constitute the last slender hope of finding beds of coal in coastal Kenya.

Nairobi,
21st September, 1956.

WILLIAM PULFREY,
Chief Geologist.

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ABSTRACT

This report describes an area of approximately 1,200 square miles situated in eastern Kenya some 60 miles inland from Malindi. It lies astride the Galana and Voi rivers, and is bounded by latitudes 3° 00′ S. and 3° 30′ S., and by longitudes 39° 00′ E., and 39° 30′ E.

The rocks exposed consist of Basement System gneisses and the overlying Duruma Sandstones which ranges in age from Permian (or possibly Carboniferous) to Triassic and is generally down-faulted against the older metamorphic rocks. The sedimentary succession consists of tillite, conglomerates, arkoses, grits, sandstones, shales and limestones, largely derived from the crystalline rocks of the Basement System and deposited in glacial, fluvio-glacial, fluvial, lacustrine, paludal, and marine environments on the fringe of an unstable continental shelf. They are the Kenya equivalent of the Karroo system of south and central Africa and show lithological and stratigraphic similarities to the Permo-Triassic rocks of Tanganyika and Madagascar.

The area has been strongly faulted, the most important movements taking place in post-Triassic times.

An account is given of the petrography, stratigraphy, correlation, genesis, and structures of the various rocks, and their economic prospects are assessed with particular reference to coal and oil.

GEOLOGY OF THE MID-GALANA AREA

I—INTRODUCTION

General.—Between October, 1952, and April, 1953, a geological survey was made of the area described in this report, which is the north-west quarter of Degree Sheet 66 (Kenya) (Directorate of Colonial Surveys Sheet No. 191), bounded by longitudes 39° 00′ E., and 39° 30′ E., and by latitudes 3° 00′ S., and 3° 30′ S. It is approximately 1,200 square miles in extent and lies astride the Galana and Voi rivers some 60 miles inland from the Kenya coast.

The greater part of the area lies within the Taita and Kilifi districts of Coast Province. The district boundary follows a north-north-easterly direction across the map area (Fig. 1), and is closely followed by the eastern limit of the Royal Tsavo National Park. The extreme north-west corner of the area is part of the Kitui District of Southern Province, and is also included in the Royal Tsavo National Park.

Methods of Mapping and Maps.—Existing topographical maps referring to the area are:—

1:250,000, Mackinnon Road–Malindi, Sheet South A-37/V & W

1:500,000, Voi, E.A.F. No. 1552

1:1,000,000, Nairobi–Mombasa, S.A.37.

On each of these sheets few details are recorded in the Mid-Galana area and in these circumstances the survey was materially assisted by the use of air-photographs taken by No. 82 Squadron of the Royal Air Force between May, 1948, and August, 1950. From these a base-map was prepared, control for the mosaic being obtained by plane-table resection from trigonometrical points outside the area. Topographic detail was based on barometric spot-heights standardized to sea-level and corrected for diurnal variation. Geological information was plotted directly from air-photographs on kodatrace flight-strips and reduced to map scale by pantograph.

Communications.—The area can be most conveniently entered from the west by the Voi entrance to the Royal Tsavo National Park. From the main gate an earth road runs to Kandacha Dam and Aruba Lodge on the Voi river, and thence north-eastwards to the Sala Rangers Post on the Galana river (lat. 3° 05′ S., long. 39° 11′ E.), a distance of 56 miles from Voi. Alternatively the National Park may be entered at Tsavo and the south bank of the Galana followed eastwards via Lugards Falls and Sobo Rock to Sala, a distance of approximately 60 miles. These two routes provide the only motorable roads giving access to that part of the area south of the Galana apart from charcoal-lorry tracks which enter the extreme south-eastern corner from Bamba and Maruvessi and extended to Garbete (lat. 3° 28′ S., long. 39° 18′ E.), and Mapotea (lat. 3° 24′ S., long. 39° 25′ E.).

North of the Galana an old caravan route between the Coast and South Kitui follows the course of the river to longitude 39° 08′ E. where it swings northwards away from the river and continues outside the area. This road is maintained in fair condition between Mambrui on the coast, and Matolane, beyond which it becomes an unfrequented track for which a vehicle with four-wheel drive is recommended. The distance from Mambrui to Sala is approximately 80 miles.

Climate and Vegetation.—The country is part of a great tract of semi-arid plainland, where the mean annual rainfall is of the order of 25 in. or less, lying between the Coast Ranges and the uplands of Kitui, Machakos and Taita. No records of rainfall within the area mapped are available, but figures obtained at three stations close outside its eastern and southern margins are given below. Both Bamba and Baricho are on the western margin of the coastal rain-belt and may be expected to receive rather more precipitation than the country further west.

TABLE I

Rainfall at the Margins of the Mid-Galana Area

(From records of the East Africa Meteorological Department)

	Latitude	*Longitude*	*Ht. (ft.)*	*Average Yearly Rainfall (inches)*	*No. of Years Recorded*
Baricho (Sabaki Valley)	3° 06′ S.	39° 47′ E.	220	28.00	2
Bamba	3° 37′ S.	39° 29′ E.	800	28.41	10
Samburu	3° 47′ S.	39° 16′ E.	915	24.18	19

No temperatures recorded under standard conditions have been taken in this area. At Voi (1,837 ft.), some 50 miles to the west, mean air temperatures range from 81° in February and March, to 72.5° in July and August. The highest maximum air temperatures so far recorded are 99° in February and March. Proximity to the Equator and relatively low altitude combine to give high day temperatures, but the diurnal temperature range varies between 10° and 20° so that the nights are tolerably cool.

These climatic conditions give rise to dense thorn and evergreen thicket in the east to parkland with small areas of open grassland in the west. Of the tree-species *Acacia* and *Commiphora* dominate. Their growth is generally gnarled and stunted so that they seldom exceed 25 ft. in height. Occasional *Baobab* and rarer *Euphorbia* stand above the level of the thorn-bush. During and after the rains the colours of wild aloes, flowering shrubs and bulbous rooted plants like *Adenium coetaneum* (the "desert rose"), relieve the monotonous green and brown of the scrub. They are accompanied by *Sanseviera* thicket and tufted grasses.

In the north the course of the Galana river is marked by a fringe of tall trees consisting mainly of giant acacias—*Acacia xanthophloae* or the "fever tree"—and *Piptadenia*, reaching a height of from 80 to 100 ft. Palms grow in some profusion along the river banks and include the doum palm, *Raphia*, and the wild date *Phoenix reclinata*. The tall coconut palm of the coast only appears in the Galana valley at the eastern margin of the area, near to native settlement.

Population and Fauna.—The native population of the area is small and is restricted to the Galana and Voi rivers where a few Wagiriama or Walungulu families mark the inland limits of coastal settlement. Elsewhere occasional wandering tribesmen are to be found, generally in the Galana valley where they are tempted to hunt illegally for ivory, rhino horn, meat and skins.

The preservation of game in the Tsavo National Park and the presence of flowing water in the Galana throughout the year allows the area to support a rich natural fauna. Among the larger mammals elephant, rhinoceros, and giraffe are common. Lion, leopard and buffalo are less frequently encountered but may be seen from time to time, the latter usually in small herds. Waterbuck are numerous near the Galana, whilst zebra, impala, eland and gazelle graze the parkland in the west. Crocodile infest the Galana river

II—HISTORY AND PREVIOUS GEOLOGICAL WORK

The majority of the early East African explorers followed caravan tracks extending inland from the mission station at Rabai near Mombasa to Taveta or Tsavo, via either Kasigau or Maungu. A further track led from the coast into Ukamba following the Galana river for over 70 miles and in 1890 Capt. F. D. Lugard* spent several months in clearing a trade route along the river on behalf of the Imperial British East African Company (McDermott, 1893, p. 209).† In the following year, when a survey was started to select the most suitable alignment for a railway from the coast to the interior, Lugard advocated that the Galana should be followed (Jackson, 1930, p. 154) and its possibilities were investigated.

The survey group, attended by over 380 porters, *askari*, cooks, gun-bearers, and interpreters was divided into two parties. The first, consisting of Capt. Macdonald‡, R.E., Lieut. Twining, R.E., and Sgt. Thomas (a surveyor of the Public Works Department of India), left Mombasa on 24th December, 1891, and traversed the Galana from Makongeni to Tsavo, arriving there on 18th January, 1892. In the meantime the second party including Capt. Pringle§ and Lieut. Austin|| of the Royal Engineers and Mr. F. J. Jackson¶ had left Mombasa on 18th December, 1891, and following the caravan route via Taru reached the Tsavo river on 11th January, 1892. This party then returned to the coast surveying an alternative route via the Voi river (Hill, 1949, pp. 61–62). Eventually the railway was constructed outside the southern margin of the area under reference.

In 1893, J. W. Gregory (1896, p. 207), chose the Galana route for the final part of his return journey from Mount Kenya and Baringo. On this occasion he recovered Permian molluscs from shales in the western part of the area.

The sedimentary rocks covering a large part of the area and extending southwards in a broad belt were grouped as the Duruma Formation by Stromer von Reichenbach (1896, p. 22), and were further classified by H. B. Maufe (1908) into a succession that was used as a basis in subsequent work. This succession was established as a result of traverses made in 1905–1906 on the railway section to the south of the present area.

In 1919, Prof. Gregory returned on a second visit to Kenya and in company with C. W. Hobley, W. McGregor Ross, and H. L. Sikes made further journeys in the Colony. These included one down the Galana from Voi to Lango Baya, 25 miles west-north-west of Malindi. A geological account of the Galana river section was published two years later (Gregory, 1921, p. 54).

* Later Lord Lugard.

† References are quoted on pp. 48.

‡ Later Maj.-General Sir James Ronald Leslie Macdonald, K.C.I.E., C.B.

§ Later Col. Sir John Pringle, C.B.

|| Later Brig.-General H. H. Austin, C.B., C.M.G., D.S.O.

¶ Later Sir Frederick Jackson.

A small pocket of coal was found in the Taru grits near the railway in 1911 and subsequently the Coastal Mining and Exporation Company and the Government searched for coal in the Duruma sandstones south of the Galana, but without favourable results. In 1927 a cored bore-hole was drilled by the company to 1,338 ft. near Samburu, but only thin layers of coal were found, and operations ceased in the following year when E. Parsons, who had carried out a geological reconnaissance extending to the Galana in the north, reported unfavourably on the possibilities of finding coal. As a result of his investigations Parsons postulated the successive thrusting of younger coastal sedimentary rocks over the older rocks of the hinterland, and published a map (1929, p. 67) indicating the geology of the coastal region.

Miss M. McKinnon Wood made a comprehensive fossil collection from the coastal region in 1928–29, and in 1930 extended her investigations to the Galana and Voi rivers. The results of this research are published in two monographs (McKinnon Wood, 1930, 1938), which bring together much palaeontological information concerning the Kenya coastlands and form a basis for current views on the stratigraphy and correlation of the sedimentary rocks.

The search for coal was continued in September, 1948, when J. Scott was granted an Exclusive Prospecting Licence for coal in an area extending from the Galana to the Tanganyika border. One exploratory bore-hole was sunk to a depth of 3,736 ft. at Maji ya Chumvi outside the southern margin of the area, between December, 1949, and April, 1950, but only thin lenticles of coal were located.

The geology of areas adjacent to that referred to in this report is described in Geological Survey reports by Miller (1952, Mariakani–Mackinnon Road area, on the south), Thompson (1956, Malindi area, on the east) and Caswell (1956, Kilifi–Mazeras area, on the south-east).

III—PHYSIOGRAPHY

Erosion Surfaces.—Maufe (1908, p. 3) described the coastal belt as a series of three zones or plains each slightly dissected by erosion and rising in steps one above the other towards the interior. Gregory (1896, pp. 222–3) had referred to these zones as (*a*) the Coast Plain, which is occupied by deposits of Pleistocene age, (*b*) the Foot Plaeau, which roughly coincides with a belt of Jurassic sediments, and (*c*) the Nyika or plainlands to the west of the coast ranges which embrace both a broad zone covered by the Duruma Sandstones and the crystalline rocks which in the west emerge from beneath them. The Mid-Galana area falls entirely within the latter physiographic zone. Here the Nyika is a gently undulating plain rising from less than 600 ft. in the east to approximately 1,100 ft. in the west, and having a mean gradient towards the coast of 15 ft. per mile. This is part of the end-Tertiary erosion surface recognized widely throughout much of eastern Kenya and neighbouring territories. In the coastal region it has been dated as Middle Pliocene by Caswell (1953, p. 6).

The configuration of the end-Tertiary plain is influenced by the underlying geology, deviations from an almost flat surface being an expression of contrasting resistances to erosion of the sandstones, shales and metamorphic rocks. Thus, outcrops of massive metamorphosed crystalline limestone give rise to the Kulalu group of hills in the centre of the area and, in the north, the western flank of the Lali hills is an obsequent fault-line escarpment between metamorphic rocks and Duruma sandstones (Fig. 1). Each of these hill-groups stands about 600 ft. above the mean level of the surrounding plains and has summit levels (1,300 to 1,500 ft.) comparable with those of the Taru and Shimba hills and the Coast Range north of Mombasa, all of which probably represent the denuded remnants of an erosion surface older than the end-Tertiary, and which is assumed to be the equivalent of the sub-Miocene surface of other parts of Kenya.

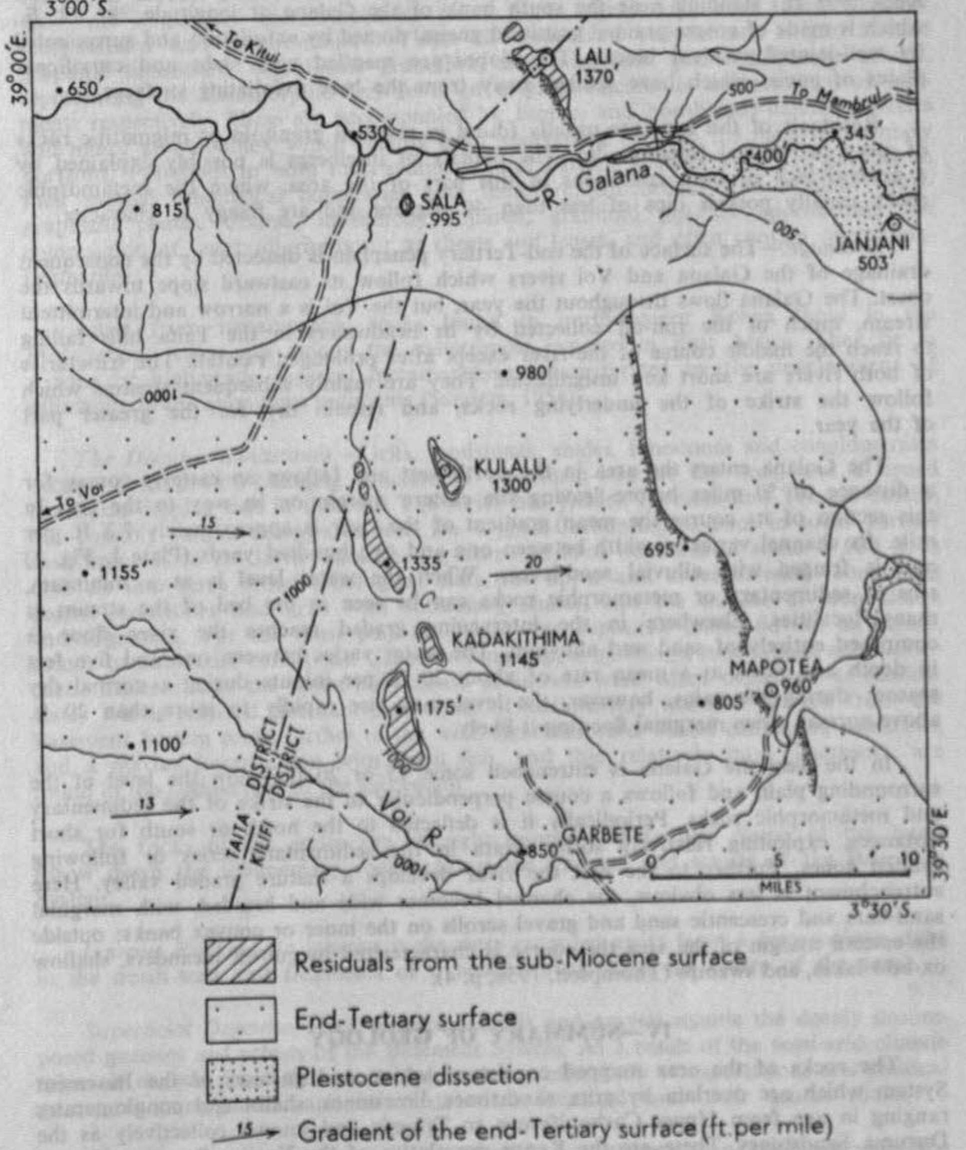

Fig. 1.—Physiographical map of the Mid-Galana area.

Inselbergs, tors, or whalebacks, a common feature of the Basement System country elsewhere in Kenya, are lacking in the Mid-Galana area. A single exception is Sala Rock (995 ft.) standing near the south bank of the Galana at longitude 39° 12′ E., which is made of coarse-grained granitoid gneiss, domed by exfoliation and surmounted by well-jointed residual blocks. The slopes are mantled with slabs and curvilinear plates of gneiss which have spalled away from the bare exfoliating surfaces.

Residuals of this type are usually found in resistant granitoid or migmatitic rocks of steep or vertical foliation dip. The paucity of inselbergs is possibly explained by a general lack of both conditions in this part of the area, where the metamorphic rocks usually possess dips of less than 40 degrees and are flaggy in character.

Drainage.—The surface of the end-Tertiary peneplain is dissected by the consequent drainage of the Galana and Voi rivers which follow its eastward slope towards the coast. The Galana flows throughout the year, but the Voi is a narrow and intermittent stream, much of the run-off collected by its headwaters in the Taita hills failing to reach the middle course of the river except after prolonged rainfall. The tributaries of both rivers are short and insignificant. They are mainly subsequent streams which follow the strike of the underlying rocks, and remain dry for the greater part of the year.

The Galana enters the area in the north-west and follows an easterly course for a distance of 50 miles before leaving the eastern margin on its way to the sea. In this section of its course the mean gradient of the river is approximately 7.2 ft. per mile. Its channel varies in width between one and two hundred yards (Plate I, Fig. 1) and is fringed with alluvial sand-levees. When the water level is at a minimum, ribs of sedimentary or metamorphic rocks can be seen in the bed of the stream at many localities. Elsewhere in the intervening graded reaches the river floor is composed entirely of sand and alluvium. The water varies between one and five feet in depth and flows at a mean rate of about 20 ft. per minute during a normal dry season; during the rains, however, the level may rise rapidly to more than 20 ft. above normal, when marginal flooding is likely.

In the west the Galana is entrenched some 15 or 20 ft. below the level of the surrounding plain and follows a course perpendicular to the strike of the sedimentary and metamorphic rocks. Periodically it is deflected to the north or south for short distances, exploiting relatively softer strata in the sedimentary series or following faulted zones. Further to the east the river develops a mature graded valley. Here entrenchment is less obvious, the channel becomes wide and braided, with marginal sand-bars and crescentic sand and gravel scrolls on the inner or convex banks; outside the eastern margin of the area the course is characterized by cut-off meanders, shallow ox-bow lakes, and swamps (Thompson, 1956, p. 4).

IV—SUMMARY OF GEOLOGY

The rocks of the area mapped consist of schists and gneisses of the Basement System which are overlain by grits, sandstones, limestones, shales and conglomerates ranging in age from Upper Carboniferous to Triassic and known collectively as the Duruma Sandstones. These are the Kenya correlative of the Karroo System of south and central Africa. Thin superficial sands, kunkar limestone and lateritic ironstone mantle the metamorphic and sedimentary rocks. In the east the Galana river has deposited narrow margins of sandy alluvium.

The Basement System.—The metamorphic rocks of the Basement System occupy approximately one-quarter of the total area and are found (i) in a wedge-shaped inlier traversed by the Galana river, and (ii) in the south-west where they emerge from beneath the Duruma Sandstones. They are crystalline gneisses, granulites, calcareous rocks and schists, comprising a series of metamorphosed sediments with associated biotitic gneisses of which the origin remains undetermined. Nearly all of them are regionally metamorphosed to a high degree and have been variably recrystallized and metasomatized. Those of undoubted sedimentary origin include graphitic limestones, calc-silicate granulites, and micaceous garnet-sillimanite schists, representing the metamorphic derivatives of original calcareous and argillaceous sediments respectively. These are accompanied by biotite- and hornblende-banded gneisses and minor amphibolites, which occupy belts intervening between the meta-sedimentary horizons. Foliations in both meta-sediments and banded gneisses alike are parallel to their mutual lithological boundaries and, therefore, concordant with original stratigraphical planes. Coarse, indistinctly foliated, granitoid gneisses approaching the composition of quartz-diorite occur as sheets and lenses, and often contain microcline-pegmatites.

Apart from metamorphic rocks found in north-eastern Kenya those in the Mid-Galana region are among the easternmost exposed in East Africa. They lie in a zone of high-grade regional metamorphism characterized by the development of sillimanite in the aluminous sediments (Sanders, 1954).

The Duruma Sandstones.—Grits, sandstones, shales, limestones and conglomerates occupy a northward-plunging syncline in the north-west of the area, and a broad coastward-dipping belt in the east. The series has yielded Permian and Triassic fossils, but possibly ranges downwards into the Upper Carboniferous and, in areas further east, upwards to the lower Jurassic. Its estimated total thickness of some 15,000 ft. is divisible into three broad lithological units, the upper and lower divisions containing coarse sandstones and grits with subsidiary shales, and the middle division shales and flagstones. For the most part the beds were deposited under fluvial, lacustrine, deltaic or sub-aerial conditions. Cross-bedding, ripple-markings, mud-cracks and worm-casts, indicate that the water-lain clastic sediments were often deposited in shallow water which received fluctuating amounts of sedimentary material derived from the Basement System rocks further to the west. Brackish-water shales containing ostracods, and a marine intercalation with fossil fish, and thin relatively pure limestones, are found in the middle part of the succession.

The rocks of the series are strongly jointed and faulted. Some of the latter throw down the sedimentary rocks against the gneisses and schists of the Basement System.

Igneous Rocks.—No igneous rocks were recorded apart from a lamprophyre dyke in the north-west and fragments of a basaltic rock from the centre of the area.

Superficial Deposits.—Red quartzose sands and gravels mantle the deeply decomposed gneisses and schists of the Basement System. As a result of the semi-arid climate minerals derived from the metamorphic rocks suffer little transportation, and residual garnet, titanomagnetite, and mica are often localized over their source rocks.

The Duruma Sandstones are less deeply decomposed than their metamorphic neighbours and are covered by thin maroon-coloured dusty soils containing more kaolin minerals and less garnet and titanomagnetite than the red soils. Over the argillaceous beds grey acidic clay-soils are developed.

Pleistocene to Recent deposits marginal to the Galana river vary from cross-bedded gravels and boulder beds containing pebbles of gneiss, sandstone, and more rarely lava, to thin alluvial fine-grained sands and muds deposited over the narrow eastern valley flats during seasonal flooding.

V—DETAILS OF GEOLOGY

1. Basement System

For convenience the Basement System rocks are described under the following headings:—

Metamorphosed Sediments
- (*a*) *calcareous rocks*
  - crystalline limestones
  - calc-silicate granulites
- (*b*) *pelitic and semi-pelitic rocks*
  - sillimanite-biotite para-gneisses.
  - garnetiferous para-granulites
  - biotite para-granulites
  - biotite para-gneisses
- (*c*) *psammitic rocks*
  - quartz-felspar para-granulites

Tectonites
- (*a*) sheared gneisses
- (*b*) mylonitic gneisses

Migmatites
- banded and contorted biotite-hornblende gneisses.

*Anatectic or palingenetic rocks**
- quartz-microcline-biotite granitoid gneisses
- pegmatites

The gneisses and schists exposed in the Galana river between Lali and Sala represent a stratiform series some 17,000 ft. in total thickness. Pelitic and psammitic rocks dominate in the section, particularly in the lower part; the middle and upper part contains calcareous gneisses and massive crystalline limestones. Throughout, the regional strike is north-north-westerly, with the foliation dipping to the west at angles of generally less than 50°. This strike-trend is that of the Mozambiquian orogenic belt (Holmes, 1951, p. 256), which extends through eastern Kenya, Tanganyika and Portuguese East Africa.

(1) Metamorphosed Sediments

(*a*) *Calcareous Rocks*

Crystalline Limestones.—Massive ash-white crystalline limestones (marbles) are found in the centre of the area from the Kulalu hills to the Galana. The largest outcrops are in the former locality where relatively resistant and steeply-dipping limestone horizons each more than 500 ft. in thickness form two ridges trending in a north-north-westerly direction. The westernmost feature is the largest, extending for over five miles and standing about 300 ft. above the surrounding plain. Much of the limestone is here a blue-grey pure limestone with individual rhombohedra of calcite reaching a size of 3 cms. A representative sample on analysis gave only 0.21 per cent magnesium oxide. Recrystallization has destroyed all evidence of original bedding in the coarser limestone, but fine-grained interstratifications contain dusty bands of graphite probably representing original carbonaceous organic material. The coarse horizons contain local concentrations of graphite, with scattered flakes ranging up to a centimetre in size.

* Footnote.—The term *anatectic* is here applied to granitoid rocks whose composition has been produced by the soaking of "emanations" into metamorphosed sedimentary and igneous rocks. Fluids entering into this process need not necessarily be of magmatic origin and may represent those present in the original rocks. The process is effectively one of alkali metasomatism. Palingenetic rocks are those produced by a culmination of antexis, whereby granitic magma is ultimately generated and emplaced at higher crustal levels.

The medium and fine-grained limestones are often impure and contain the calc-silicates diopside, epidote, actinolite, and sphene (specimen 66/462* from the Galana valley, Fig. 3b; specimen 66/466 from Kulalu). Bronze-coloured phlogopite occurs occasionally, and some horizons contain forsterite in various stages of serpentinization and replacement by carbonate (specimen 66/456, from Kulalu). A narrow band of magnesian limestone in the Galana approximately six miles south-west of the Lali hills contains up to 30 per cent of crystalloblastic forsterite which extends as tongues into and embays the enclosing calcite (specimen 66/454; Fig. 3a).

In the Kulalu area the westernmost outcrops of crystalline limestone are traversed by a series of faults the trend of which is oblique to the regional strike. They form a southward continuation of the Sala fault-zone where several hundred feet of Duruma sandstones are thrown down against the metamorphic rocks of the Basement System. Here the limestone is brecciated and veined with iron oxides in narrow zones. Lineated flinty mylonite and angular blocks of gneiss have been caught up in the limestone which shows a well-marked flow-structure. The contrasting rock types evidently responded differently to deformation, the limestone yielding by flowage, whilst the containing gneiss fractured, yielding blocks to the flowing limestone and allowing the limestone to penetrate it as veins (Fig. 2). Reaction borders between xenolithic gneiss and the enclosing limestone are skarns and contain a variety of calc-silicate minerals including diopside, epidote, hornblende, sphene, and clinozoisite. The xenoliths show all stages of dissolution from recognizable angular inclusions of gneiss to residual clusters of calc-silicates. Similar mobilized limestones occurring in the Parry Sound District of Ontario have been described by Satterly (1942).

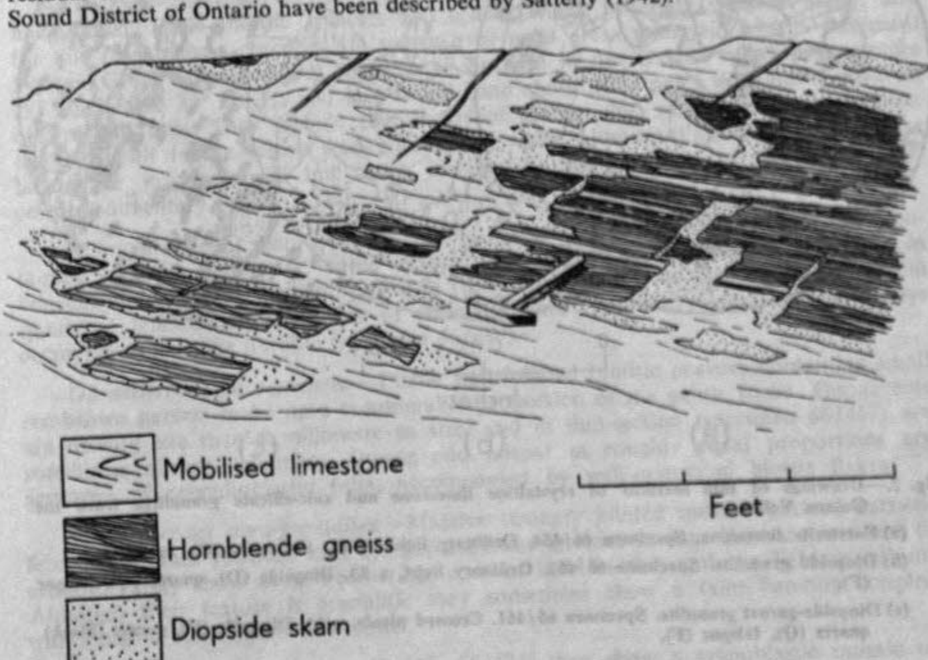

Fig. 2.—Mobilized crystalline limestone with enclosed blocks of hornblendic gneiss. Western Kulalu Hills.

* Specimen numbers 66/462, etc., refer to material in the regional collections of the Geological Survey, Nairobi.

Calc-silicate Granulites.—Among the metamorphic rocks exposed in the Galana between longitudes 39° 12′ E., and 39° 18′ E., only one horizon of crystalline limestone was recorded (represented by specimen 66/454, *see* Fig. 3a). The neighbouring gneisses and granulites in this locality are nevertheless notable for their calcareous character, and it is likely that they represent the continuation of a zone of metamorphosed calcareous sediments which include a greater thickness of crystalline limestone in the Kulalu hills ten miles to the south.

The calc-silicate granulites are resistant rocks forming conspicuous outcrops in the Galana river. They are medium-grained and indistinctly foliated, varying in colour from dark green to blue-grey dependent on the amount of contained felspar. Medium plagioclase usually accounts for about half the mineral composition and is commonly accompanied by diopside, epidote, hornblende, sphene and garnet. The most abundant dark mineral is a coarsely granular, weakly pleochroic diopside which often shows alteration to hornblende (specimen 66/463). Dense purple granulites containing salmon-pink garnet intergrown with diopside occur in thin bands (specimen 66/461; Fig. 3c).

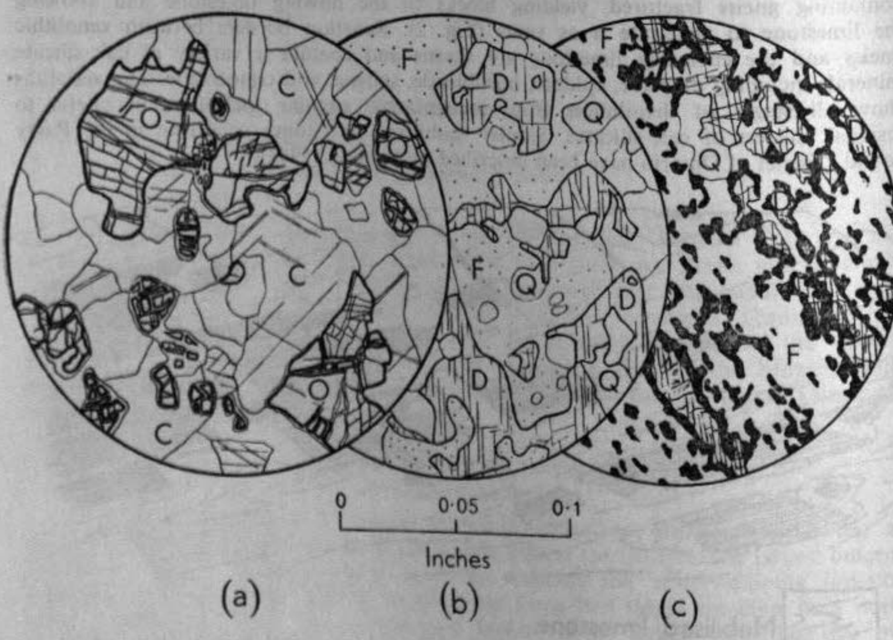

Fig. 3.—Drawings of thin sections of crystalline limestone and calc-silicate granulites from the Galana Valley.

(a) Forsterite limestone. Specimen 66/454. Ordinary light, x 13. Forsterite (O), calcite (C).

(b) Diopside granulite. Specimen 66/462. Ordinary light, x 13. Diopside (D), quartz (Q), felspar (F).

(c) Diopside-garnet granulite. Specimen 66/461. Crossed nicols, x 13. Diopside (D), garnet (black) quartz (Q), felspar (F).

Apart from a greater proportion plagioclase, the presence of little calcite and an apparent lack of forsterite, these granulites contain a closely similar mineral suit to the impure limestones referred to above (p. 9). This similarity together with the replacive textures of plagioclase and the presence of microcline imply that their composition has been attained by the metasomatism of original limestones, or other highly calcareous rocks.

Some visually estimated modes are as follows:—

	66/461 Per cent	66/462 Per cent	66/463 Per cent
Quartz	—	8	15
Microcline	—	5	5
Plagioclase (Ab_{25} to Ab_{60})	60	65	55
Diopside	15	15	10
Hornblende	—	3	8
Epidote (inc. zoisite)	4	—	2
Sphene	—	2	3
Garnet	15	2	1
Scapolite	3	—	—
Calcite	3	—	—
Biotite	—	—	1

66/461 Garnet-diopside granulite. Galana R., at long. 39° 15′ E.
66/462 Diopside granulite. Galana R., at long. 39° 14′ E.
66/463 Diopside-hornblende granulite. Galana R., at long. 39° 14′ E.

(*b*) *Pelitic and semi-pelitic Rocks*

Rocks in the area derived from argillaceous sediments are dark, medium- to fine-grained, fissile biotitic gneisses and schists which generally weather easily, and for this reason their outcrops are scarce over most areas underlain by the Basement System. Good exposures are, however, to be seen in the Galana between longitudes 39° 16′ E. and 39° 18′ E., and in a broad zone about three miles west and south-west of the Lali hills. They include thin bands of garnet- and sillimanite-bearing schists together with biotite schists and gneisses in which alumino-silicates and garnet are lacking or inconspicuous, but which are nevertheless probably of pelitic or semi-pelitic sedimentary origin.

Sillimanite-biotite para-gneisses.—These are grey biotitic schistose gneisses containing quartz, plagioclase, some orthoclase, and biotite. Sillimanite is found in concentrations on the foliation planes, where it often forms clusters and wisps in quartzose lenticles. Stout prisms of sillimanite are rare, the mineral nearly always occurring as hair-like fibrolite (specimen 66/489).

Garnetiferous para-gneisses.—Fissile well-foliated biotitic gneisses containing small red-brown garnets make up a considerable proportion of the pelitic rocks. The garnets are usually less than a millimetre in size, and in thin-section (specimen 66/457) are sometimes almost colourless. Quartz and felspar in roughly equal proportions are arranged in crystalloblastic folia, accompanied by well-orientated biotite flakes.

Garnetiferous para-granulites.—Massive strongly jointed medium-grained garnetiferous granulites contrast with the garnetiferous gneisses in that they are resistant to erosion, rarely show deep weathering, contain little biotite, and are light in colour. Although their texture is granulitic they sometimes show a faint banding coupled with a planar concentration of garnet.

In thin-section (specimens 66/465, 66/474) they show a granoblastic mosaic of quartz, microcline, and oligoclase, with scattered pink garnets and occasional biotite.

Biotite para-gneisses.—Medium-grained grey biotitic gneisses interstratified with garnetiferous and alumina-rich types are also attributed to a pelitic or semi-pelitic derivation. In thin section they are seen to contain quartz segregated in folia or forming elongated grains, together with oligoclase and biotite.

The proportions of minerals present in the gneisses and granulites vary from band to band, but an idea of the range of composition is given below. Some estimated modes for the pelitic and semi-pelitic rocks from the Galana valley at longitude 39° 17′ E. are as follows:—

	66/457 *Per cent*	*66/465* *Per cent*	*66/489* *Per cent*
Quartz	40	40	45
Orthoclase	6	—	5
Microcline	—	7	—
Plagioclase (Ab_{75} to Ab_{91})	46	48	37
Biotite	5	1	5
Garnet	3	2	—
Sillimanite	—	—	5
Muscovite	—	—	2
Magnetite	—	2	1

66/457 Garnetiferous para-gneiss.
66/465 Garnetiferous para-granulite.
66/489 Sillimanite-biotite para-gneiss.

(c) *Psammitic Rocks*

Quartz-felspar para-granulites.—Massive pink- and brown-weathering granulites, occurring as resistant bands in the metamorphic succession, represent original sandstones or grits, to which they have superficial resemblances, occasionally preserving rounded grains of clastic quartz, and bedding features. Beneath a thin weathered crust they are nearly always tough and undecomposed.

Specimen 66/477, from one mile south-west of the summit of Lali, is typical of these granulites. A thin section shows a granoblastic mosaic of quartz and felspar in approximately equal proportions. Microcline and microcline-microperthite form at least 10 per cent of the rock, the remainder of the felspar being oligoclase. Virtually no dark minerals are present.

(2) Tectonites

(a) *Sheared Microcline Gneisses*

The Basement System rocks in the Mid-Galana area are traversed by a series of deep shear-zones in which some of the crystalline gneisses have been raised to a plastic condition attended by at least partial recrystallization, whilst others have yielded by fracture and cataclasis. One such zone can be followed from a few hundred yards west of Sala in a southerly direction to a point between Hadakithima and Duharu, a distance of over 20 miles. In this zone the metamorphic rocks are closely foliated and have a strong lineation produced by the intersection of foliation and shear-planes. They are usually medium-grained, light-coloured, or pink dappled, and have the superficial appearance of normal quartzose para-gneisses. In thin section (e.g. specimen 66/478), they are found to contain strain-polarising quartz aggregates arranged in lenticular folia. In some specimens the inter-crystalline borders are ragged and interlocking and the crystal margins are granulitized. Besides quartz the sheared gneisses contain abundant microcline-perthite and oligoclase, much of which is of post-tectonic crystallization, although some crystals of both felspars show distortion of twin lamellae and mortar-structure. Planes of maximum shear in the rock are distinguished by wavy or undulating zones of finely granulitized quartz and felspar accompanied by micas and chlorite.

(b) *Mylonitic Gneisses*

The mylonitic gneisses are grey, fine-grained, flaggy rocks with a flinty fracture, often preserving a very pronounced lineation on joint-faces. In thin section they show a granular mass of angular cataclastic quartz and felspar crystals showing internal distortion. The granules are enclosed in a shredded submicroscopic matrix of rock flour with micas and chloritic minerals (specimen 66/479). These rocks have suffered mechanical deformation with little or no post-tectonic recrystallization and differ from the sheared gneisses in containing little microcline. They were probably produced at relatively shallow depth during later movements on the old shear-zones.

(3) Migmatites

Biotite-hornblende Banded and Contorted Gneiss.—Where it is well exposed in the Galana river much of the metamorphic series is recognizable as originally a sedimentary succession, in which migmatitization is not evident to any extent. In an area three miles north-east of Sala, however, biotitic flaggy gneisses merge across the strike into banded gneisses in which dark biotite-hornblende bands are differentiated from light-coloured quartzo-felspathic ribs, bands and veins. The contrasting bands are evenly preserved along the strike and conformable to the foliations in the neighbouring meta-sedimentary gneisses and schists. In other exposures contortion of the gneiss is evident and here dark bands are often drawn out into streaky *schlieren*, or ruptured into sub-angular fragments. The quartzo-felspathic portion which is granodioritic in composition, varies in texture from fine-grained to coarsely crystalline, the coarsest material being invariably localized where there has been a reduction in pressure during movement of the migmatite. These low pressure sites are generally found in shear-zones, at local swellings, arches of ptygmatic folds, and intervening between biotite-amphibolite bands which have suffered rupture and been drawn apart into *boudins*. In these instances the quartzo-felspathic component is pegmatitic in appearance, but in composition is closely similar to the normal light-coloured bands containing quartz, microcline, sodic oligoclase, biotite and hornblende. In specimen 66/485 microcline is abundant and has replaced both quartz and plagioclase.

Sometimes the light-coloured migmatitic bands are broad and coarsely crystalline, and contain thin internal stringers of biotite parallel to the foliation of the enclosing gneiss. The stringers are evidently remnants of the country-rock and prove that some of these veins are conformable replacement pegmatites.

Nodules which are either diopsidic or sillimanitic are occasionally found arranged in zones in the migmatites. It is likely that they represent respectively calcareous and pelitic meta-sedimentary relics. Their presence indicates that much of the biotitic banded material in the migmatites is probably of original sedimentary origin.

(4) Anatectic or Palingenetic Rocks

(a) *Granitoid Gneisses*

Coarse-grained pink granitoid gneisses outcrop at the western margin of the metamorphic inlier between the Galana river and Kulalu, and also in the south-western corner of the area. Gneisses of this type are resistant to erosion and, in consequence, are often the only rock to be seen *in situ* over much of the Basement System terrain. At Sala (995 ft.) they form a bold inselberg overlooking the Galana. Here the gneisses are reddish-pink and massive, with an indistinct foliation parallel to the regional strike of the surrounding metamorphic rocks. Many of the visible quartz and felspar crystals reach a size of half a centimetre.

From Sala a belt of similar gneiss can be followed northwards into the Galana where it outcrops in the river close to the faulted boundary between Basement System rocks and Permian sediments. In thin section (specimen 66/480) the essential constituents are revealed as quartz, microcline-perthite and oligoclase. The total felspar exceeds the quartz, the principle mineral being potash-perthite in large well-developed sub-euhedral metacrysts which impart a pink colour to the rock. Myrmekite intergrowths are common between quartz and felspar. Biotite is also present in large intergranular flakes arranged in poorly defined folia, and biotite-rich *schlieren* were noted in both the Sala and Galana exposures.

This belt of granitoid gneiss is less than half-a-mile in width, and in the east is margined by banded migmatite forming a transitional zone to meta-sediments. Much of the intervening migmatite contains replacive potash felspar which is even more abundant in the granitoid gneiss. Such a composition appears to have been attained by a culmination of potash metasomatism in a narrow zone parallel to the boundary faults and their associated sheared microcline gneisses.

(b) Pegmatites

Pegmatites are found in both the granitoid gneisses and migmatites, and occasionally as thin veins in the metamorphosed sedimentary rocks. No pegmatite was recorded in the Permo-Triassic rocks. They can be classified into two compositional types:—

(i) Soda pegmatites.

(ii) Potash pegmatites.

(i) *Soda Pegmatites.*—These are restricted to the migmatites, and biotite schists and gneisses of possible sedimentary origin. In mineral composition the soda pegmatites closely resemble their host-rocks, containing quartz, albite-oligoclase, and biotite. In the biotite gneisses they form thin conformable veins or sheets, and in the migmatites are often developed in lenticular swellings and localized shear-zones. Occasionally they are seen to cut across the banding or foliation of the host-rock without producing displacement of the bands, when they are demonstrably non-dilational and have evidently grown by replacement. Sometimes the contact between pegmatite and host-rock is dark with biotite and/or hornblende, which probably represents ferromagnesian material "filtered-off" during pegmatite growth.

Large almandine garnets noted in a comformable pegmatite located in garnetiferous pelitic gneiss in the Galana at longitude 39° 16′ E. suggest that the body represents a localized recrystallization and metasomatism of the enclosing gneiss.

(ii) *Potash Pegmatites.*—Massive pink pegmatites measuring up to several feet across occur in the Sala granitoid gneiss. They contain microcline-perthite, quartz, and occasional albite-oligoclase. Most are conformable to the foliation of the enclosing gneiss and have margins in which biotite occurs in large flakes and books up to two inches across. Like the soda-pegmatites the potash group are very similar in composition to their host, and it is evident that both represent a redistribution of the mineral constituents of the country-rock, aided by metasomatism, rather than injection of pegmatitic material from below.

2. The Duruma Sandstones

The Duruma Formation (Duruma Sandstones of later authors) was so named by Stromer von Reichenbach (1896, p. 22). It covers the greater part of the present area and comprises conglomerates, arkoses, sandstones, shales and limestones that seem for the most part to have been deposited in the fluvial, lacustrine, deltaic, and neritic environments of an unstable continental shelf. Three major lithological divisions are distinguishable, with coarse sandstones and grits at the top and bottom of the succession and finer sandstones and shales in the middle:—

Duruma Sandstones	Upper	4. Mazeras Sandstones and Shimba Grits
	Middle	3. Mariakani Sandstones 2. Maji ya Chumvi Beds
	Lower	1. Taru Grits

The regional dip is eastwards towards the coast and, although the continuity of the section is interrupted by strike-faults producing local repetition, the cumulative effect of the coastward dip is to expose successively higher beds towards the east. Only the lower and middle divisions are found within the Mid-Galana area, outcrops of the upper divisions falling outside the eastern boundary.

The stratigraphy of the lower and middle divisions is summarized below in Table II.

TABLE II.—THE DURUMA SANDSTONES OF THE MID-GALANA AREA

Series	Group	Thickness in feet
Mariakani Sandstones	7. *Mottled Sandstone Group.*—Current-bedded, micaceous, poorly cemented sandstones. Unfossiliferous. Conglomerate and interformational breccias at base	2,500
	—Unconformity and Overlap—	
Maji ya Chumvi Beds	6. *Upper Shale and Flagstone Group.*—Shales and flagstones with *Estheria.* Marine neritic beds with *Eotriassic fish*	2,800
	5. *Lower Shale Group.*—*Palaeanodonta* beds, carbonaceous shales, thin calcareous sandstones, limestones. *Voltzia, Ullmania*	2,000
	—Disconformity—	
Taru Grits	4. *Calcareous Group.*—Calcareous flagstones, thin siliceous limestone, oolitic limestone	500
	3. *Sandstone Group.*—Conglomerates, felspathic sandstones, calcareous sandstones, mudstones	2,000–3,000
	—Probable Unconformity—	
	2. *Arkose Group.*—Thick arkose wedges grading upwards into felspathic grits, and carbonaceous shales with carbonized plant remains	1,000–4,000
	1. *Basal Group.*—Conglomerate, arkose, tillite	100–200
	—Unconformity—	
		10,900–15,000

(1) THE TARU GRITS

The Taru Grits cover a wide extent in the north-west and centre of the area and unlike the metamorphic rocks of the Basement System provide numerous scattered outcrops, boulders, and joint-slabs over much of the surface. The best exposures are to be found in the Galana river from the western margin of the area to approximately longitude 39° 4′ E. and, again, in a section of the river due south of the Lali hills. Extensive exposures are also to be seen in the Lali hills themselves and in the Hadakithima and Garbete areas.

This dominantly arenaceous series consists of a variety of clastic sediments often showing considerable lithological contrast. They are described in order of their respective groups from the base upwards.

(*a*) *Basal Group.*—Eastward-dipping Lower Duruma Sandstones are found well to the west of the present area and for this reason little is seen of the base of the succession apart from a few exposures in the extreme south-west where faulting may conceal the lowermost beds. The faulted inlier of metamorphic rocks exposed between Sala and the Lali hills has, however, remnants of the basal sedimentary beds preserved on it. These can be seen in a small hillock situated two miles due west of Lali summit where a thickness of over 100 ft. of massive pale grey-, yellow-, and maroon-weathering indurated rocks rests unconformably on gneisses of the Basement System. The outcrop, measuring no more than 400 yards across, is surrounded by gneisses and apparently occupies a small depression on the pre-Karroo surface. It is poorly stratified, consisting of unsorted, angular, faceted, often triangular or pentagonal fragments of translucent quartz, felspar, and gneiss, measuring up to two inches across. These are enclosed in a matrix which itself consists of smaller sharply angular phenoclasts, and a sub-microscopic paste of silicified rock-flour and clay material. In thin section (Fig. 4a and specimens 66/464, 66/481, 66/482) the rock very closely resembles the Permian Dwyka Tillite of South Africa (*vide* Pettijohn, 1949, Plate 13, C). It possesses typical tillite features, i.e. (i) lack of stratification, (ii) unsorted, angular, undecomposed constituents which are more local than foreign in derivation, and (iii) a pale grey matrix, such as is characteristic of sediments deposited under glacial conditions, with sharp-edged particles set in a fine-grained paste. It differs from the overlying arkose of the series in showing a wider size variation between individual enclosed rock fragments, and a higher ratio of fine-grained matrix to larger fragments. The matrix is comminuted material, essentially an unsorted gouge caused by attrition at the base of an ice-sheet which moved over the metamorphic rocks.

The greatest thickness of till was probably preserved in depressions on the sub-glacial floor from which it was either partly removed by subsequent erosion or concealed by later deposition and down-faulting of the Permo-Triassic rocks. No striated pebbles were recovered from the rock, but a few were observed and photographed.

Varved siltstones can be seen in cliffs on the north bank of the Galana at longitude 39° 18′ E. The exposures are some of the lowest observable in this part of the Taru grit and are situated some four miles to the south-east of the tillite outcrop. The varved nature of these rocks is not immediately apparent since the brown-weathering surfaces show little sign of lamination. The fresh interior is, however, strongly differentiated into delicate alternations of brown sandy silt and grey clay, the couplets of which maintain a characteristic thickness and also preserve the ratio between their constituent coarse and fine portions. The former are generally thicker than the fine dark clay lamellae and probably represent sand and silt carried by melt-waters into a glacial lake, whilst the latter were formed during the settling of the finest suspended matter during each subsequent seasonal freezing of the lake waters.

(*b*) *Arkose Group*.—In its lower part this group consists of coarse clastic material derived from a rapidly wasting gneiss terrain. Conglomerate and arkose dominate. The conglomerates are polymict with well-rounded pebbles and cobbles of quartz, migmatite, and granitoid gneiss, set in a gravel or coarse arkose matrix. Some of these conglomeratic gravels probably represent glacial outwash as they are poorly sorted, unstratified, and contain abundant interstitial felspathic sand. False-bedding and high depositional dips in the extreme west of the area give the impression that arkose and felspathic grit are of great thickness, and whilst there can be no doubt that they attain a considerable thickness near their source in the west, they thin rapidly towards the east, with an attendant reduction in mean dip. They probably form a series of wedges or coalescing fans of rapidly buried terrestrial material and give way upwards to alternating felspathic grits and carbonaceous shales containing coalified plant remains. The shale horizons are sometimes contorted, or disrupted and fragmented, as a result of slumping before final consolidation.

The arkose is typically coarse-grained and grey or pink in colour inside a yellow or reddish-brown oxidized crust. The main constituents can be distinguished by the unaided eye. In thin section the contained felspar is seen to exceed 25 per cent and in some specimens reaches 50 per cent; it includes microcline, and plagioclase ranging from albite to andesine. Both felspar and quartz occur in angular grains and show a poor to moderate degree of sorting (Fig. 4b, specimen 66/493 from the Voi–Sala road, 12 miles from Sala). Accompanying minerals are garnet, biotite, muscovite, sericite, magnetite, tourmaline, and rutile. The cement is generally calcareous (as in specimen 66/493), but in some very coarse varieties is also ferruginous (specimen 66/492, from one mile north of the Voi river at 39° 7′ E.).

The felspathic grits overlying the arkose are brown or purple weathering and contain more than 20 per cent of felspar, so that they too could be classified as arkose, but compared with the basal arkose the sorting of their constituents is better,

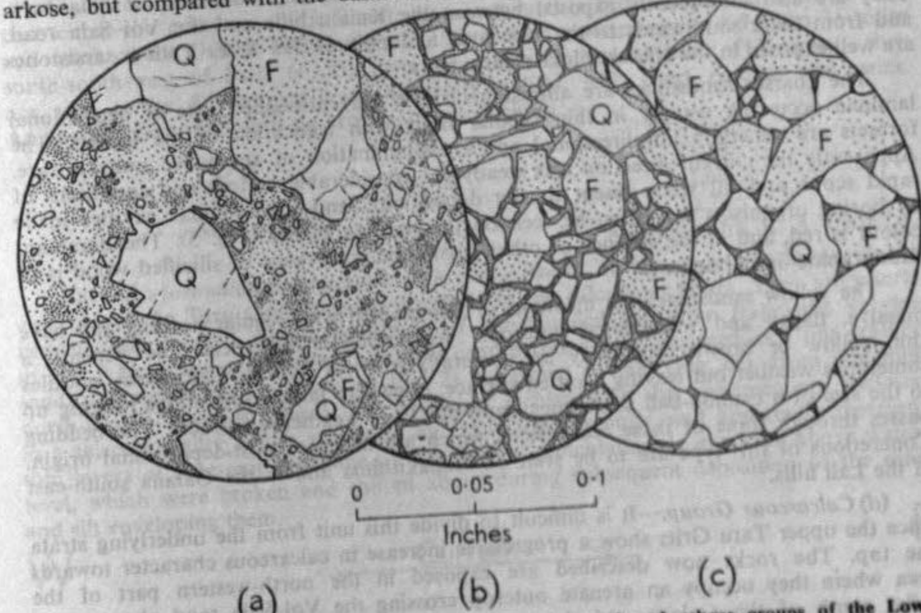

Fig. 4.—Drawings of thin sections of sediments from the basal and arkose groups of the Lower Duruma Sandstones.

(a) Tillite. Specimen 66/481, from two miles west of Lali. Ordinary light, x 13. Quartz (Q), felspar (F).

(b) Arkose. Specimen 66/493, from the Voi-Sala Road, 12 miles from Sala. Ordinary light, x 13. Quartz (Q), felspar (F).

(c) Felspathic grit. Specimen 66/494, from the western foot of the Lali hills. Ordinary light, x 13. Quartz (Q), felspar (F).

individual quartz and felspar grains are less angular, and the intergranular spaces are much reduced, most of the mineral granules being in mutual contact (Fig. 4c, specimen 66/494 from the west foot of the Lali hills). The cementing material is usually calcareous. The grits are sometimes cross-bedded, massive, and gravelly, but often are medium-bedded and alternate with shales and mudstones; immediately outside the western margin of the area mapped they are graded (*see* Fig. 7). The thickness of each grit bed in the Galana river between longitude 39° E. and 39° 2′ E. ranges between one and four feet. In the lower part of the group shales are subordinate, but as the section is ascended argillaceous intercalations become thicker. The lower shales are gritty and carbonaceous, sometimes containing glistening black coalified plant remains on their division-planes. These cyclic shales were evidently deposited during periods when coal-forming conditions applied, but the duration of each period was too short to permit the accumulation of sufficient vegetable matter to form even thin coal seams. Some of the sandstones contain iron-bearing lenticles (specimen 66/490, from the Galana river at longitude 39° 1′ E.), which is also a feature of the Lower Coal Measures in Tanganyika (Songea) and Madagascar.

(c) *Sandstone Group.*—This is a substantial unit of the the Taru grit formation in the Mid-Galana area. At the base it contains thin conglomerates and coarse felspathic grits followed by coarse current-bedded sandstones weathering red, purple, and sometimes green, which are followed by yellow flaggy calcareous sandstones. The entire succession has intercalations of thin blue or green mudstones.

The best exposures of the sandstones are to be seen in the Galana between longitudes 39° 2′ E. and 39° 5′ E., in an area of several square miles south of the game-rangers' post near Sala, and from two to five miles south-west of Sala rock. They are also infrequently exposed between the Kulalu hills and the Voi–Sala road, and from there southwards to the Voi river at longitude 39° 8′ E. Yellow sandstones are well exposed in the Hadakithima escarpments.

The coarser sandstones are almost invariably current-bedded, sets of depositional laminae occurring usually in thin tabular units with truncation of the topsets. The foresets are generally uni-directional and cross-lamination of successive units is rare. Apparently the current direction was steady for considerable periods and conditions of rapid scour and fill were absent during deposition. Sand-filled tubular cavities made by boring organisms can often be seen on the bedding planes (Fig. 5). The dominant colour is red, and in the absence of other fossils the occurrence of silicified wood is of stratigraphic importance.

The yellow sandstones are medium- or fine-grained with regular bedding and have massive, flaggy and well-jointed outcrops. Weathering is superficial and beneath a thin yellow or brown crust they are generally grey in colour. Calcareous nodules sometimes weather out leaving a pitted surface, elsewhere larger concretions ranging up to the size of a cannon-ball sometimes stand out from weathered surfaces. The bedding passes through some of these concretions which are hence of post-depositional origin. Concretions of this type are to be seen on Hadakithima and in the Galana south-east of the Lali hills.

(*d*) *Calcareous Group*.—It is difficult to divide this unit from the underlying strata since the upper Taru Grits show a progressive increase in calcareous character towards the top. The rocks now described are exposed in the north-western part of the area where they occupy an arcuate outcrop crossing the Voi–Sala road about seven miles south of the Galana and then swinging north-westerly towards the river at longitude 39° 5′ E. Here the rocks are thin-bedded and include sandstones, calcareous grits, gritty limestones, oolitic limestones, cherty limestones, and intra-formational limestone breccias. They are intercalated with micaceous mudstones and gritty shales.

The calcareous grits are grey in colour possessing a characteristic granular-weathering surface where clastic quartz and felspar stand out from an enclosing calcareous matrix. The weathered skin is extremely thin and the rock beneath is fresh, with clean glistening fracture surfaces. In thin section (specimen 66/483 from six miles south of the rangers' post), it is seen that angular to sub-rounded well sorted granules of quartz and felspar are enclosed in a calcareous matrix which comprises some 40 per cent of the rock. In the gritty limestones the proportion of calcareous matrix increases to over 50 per cent (specimens 66/496 from seven miles south of the rangers' post, Fig. 6b, and 66/497 from six miles west of Kuwetu). The purer limestones have narrow outcrops and are dark grey, maroon or black in colour. They have a hackly or conchoidal fracture, and often break with smooth glistening surfaces. They are of three kinds:—

(i) Oolitic limestones.

(ii) Cherty limestones.

(iii) Intra-formational limestone breccias.

(i) *Oolitic Limestones*.—Specimen 66/484 (Fig. 6a) is from a black limestone outcropping in the Galana about one mile east of Sala rangers' post. It is visibly bedded and contains ooliths up to 2 mm. across. In thin section the limestone is seen to be impure, containing between 10 and 15 per cent of clastic quartz and felspar as well as flakes of brown mica, the remainder consisting of a calcareous matrix with ooliths having a well defined concentric structure.

Specimen 66/495 is a maroon-coloured oolite outcropping about seven miles north-west of Kulalu hill. It is coarse and ferruginous, and contains approximately 10 per cent of non-calcareous clastic material together with large calcareous ooliths some of which have quartz and some felspar nuclei.

(ii) *Cherty Limestones.*—Black, dense limestones containing less clastic material than either the gritty or oolitic limestones occur in thin beds south-south-west of Sala and south of the Galana at 39° 5′ E. In thin section (specimens 66/499 from 3½ miles south-south-west of Sala, 66/501 from 4½ miles south-south-west of Kuwetu), they are seen to be fine-grained and incipiently oolitic, with chert patches and veins. An analysis gave the following proximate composition:—

	Per cent
$CaCO_3$	83.10
$MgCO_3$	1.60
SiO_2	12.29

Analyst—Mrs. R. A. Inamdar.

(iii) *Intra-formational Limestone Breccias.*—Rocks of this type are found at the very top of the Taru Grits forming interbeds in the calcareous strata. They are poorly bedded and dappled with a multitude of sub-rounded limestone fragments varying in size from a few millimetres to several centimetres across, enclosed in a fine-grained sandy calcareous matrix (Plate II, Fig. 2). Specimen 66/500 (Fig. 6c), from one mile north-west of Sala, is typical. The limestone inclusions in this specimen are enclosed in a felspathic silty matrix cemented by calcite and limonite, and apparently represent thin layers of lime-mud and lime-silt lithified by cementation or exposure above water-level, which were broken and shifted about during subsequent deposition of the sand and silt enveloping them.

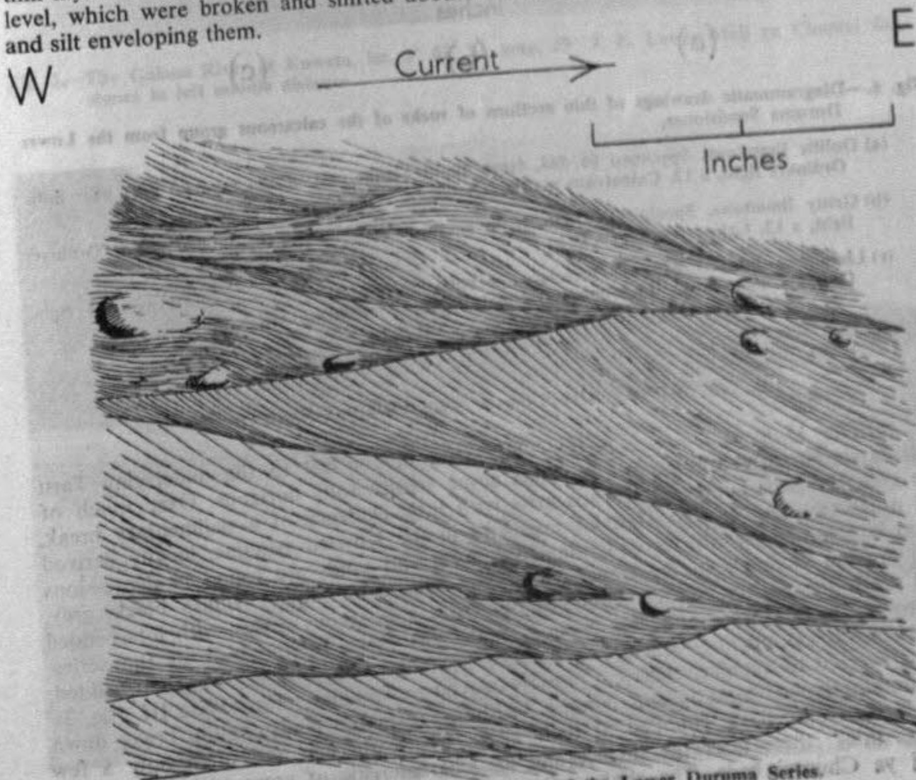

Fig. 5.—Current bedding in sandstones of the Lower Duruma Series.

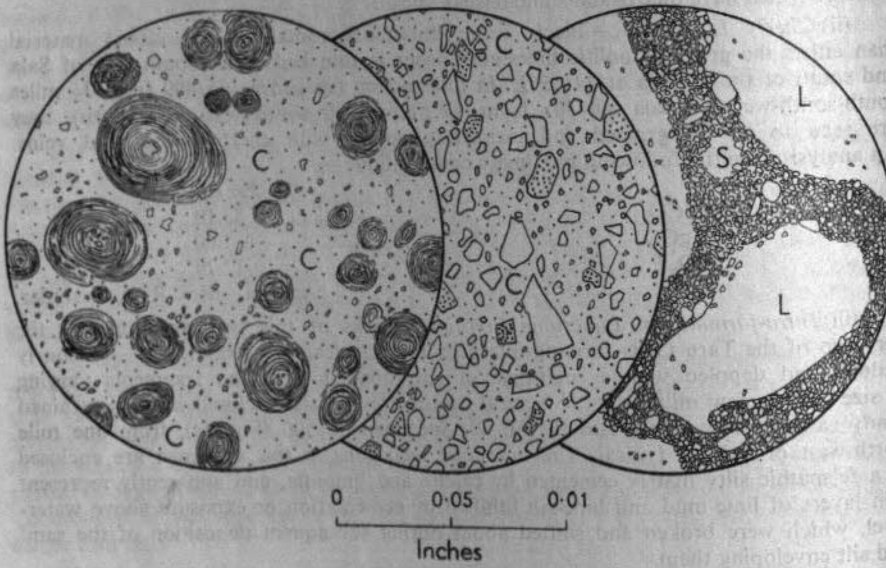

Fig. 6.—Diagrammatic drawings of thin sections of rocks of the calcareous group from the Lower Duruma Sandstones.

(a) Oolitic limestone. Specimen 66/484, from about a mile east of the rangers' post near Sala. Ordinary light, x 13. Calcareous matrix (C).

(b) Gritty limestone. Specimen 66/496, from seven miles south of the rangers' post. Ordinary light, x 13. Calcareous matrix (C).

(c) Limestone intra-formational breccia. Specimen 66/500 from a mile north-west of Sala. Ordinary light, x 13. Lime-mudstone inclusions (L), siltstone matrix (S).

(2) The Middle Division of the Duruma Sandstones

(*a*) *The Maji ya Chumvi Beds.*—This series in contrast to the underlying Taru grits is dominantly argillaceous and has some fossiliferous horizons. Over much of the area the beds succeed the Taru grits with little evidence of a sedimentary break, but north-east and east of Hadakithima, and in the Kuwetu syncline, locally derived basal conglomerates with cross-laminated gravels and sands are found in depressions and erosion channels in the upper Taru grits (Plate IV, Fig. 1). Bluish black, grey, and green-grey, gritty, micaceous and sometimes carbonaceous shales, with interbedded yellow-white flagstones and thin-bedded sandstones make up the bulk of the series. The sandstones and flags are often ripple-marked (Plate III, Fig. 1) or current-bedded, and traversed by regular, clean-cut, closely spaced rectangular joints (Plate III, Fig. 2). A combination of jointing and laminar bedding causes the sandstones to break down into rectangular flags, rounded at their edges by weathering, and often only a few inches thick; these litter the surface and are characteristic of areas underlain by the Maji ya Chumvi beds. The shales often weather to a brown or olive-drab colour

PLATE I

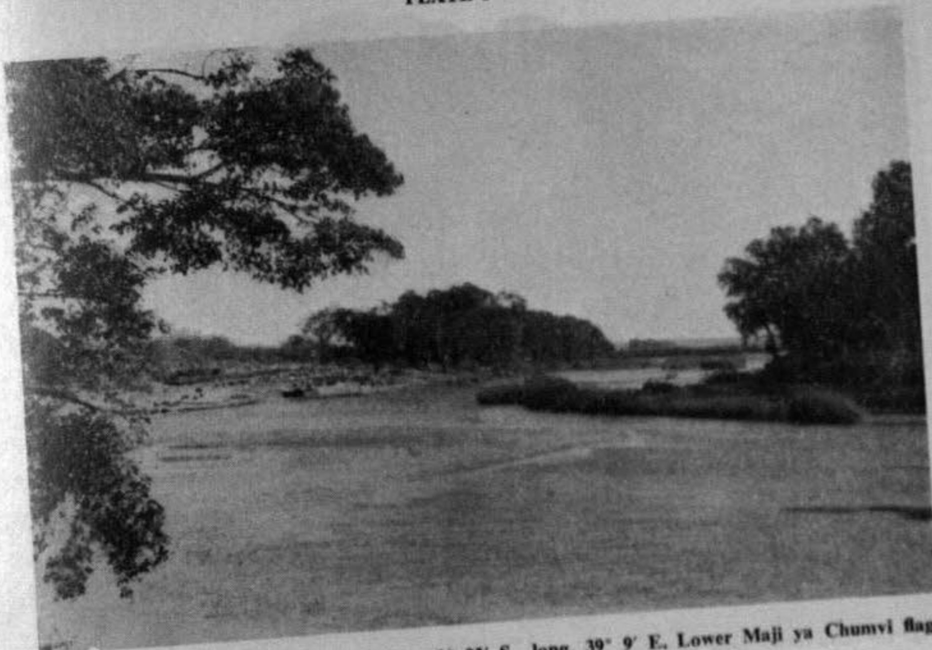

Fig. 1.—The Galana River at Kuwetu, lat. 3° 02′ S., long. 39° 9′ E. Lower Maji ya Chumvi flagstones in left middle distance.

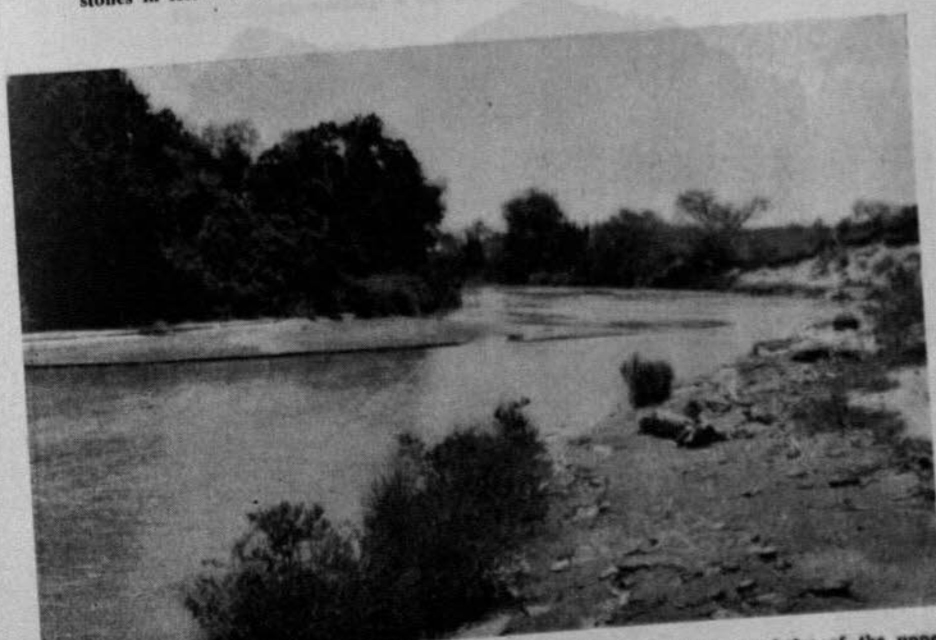

Fig. 2.—The Galana River at lat. 3° 04 S., long. 39° 22 E. Black *Estheria* shales of the upper Maji ya Chumvi Beds in right foreground.

PLATE II

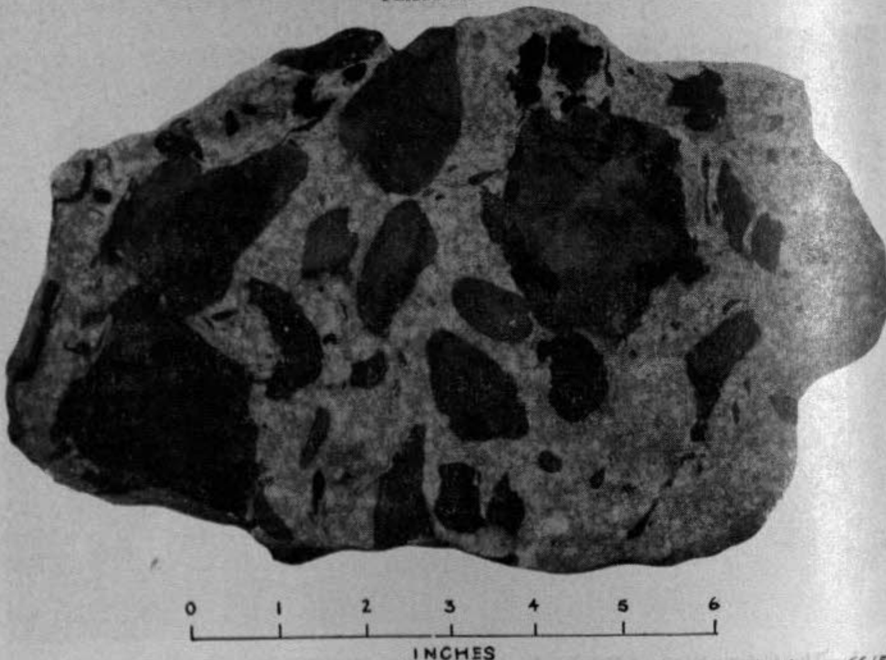

Fig. 1.—Intra-formational shale conglomerate from the Mariakani Sandstones. Specimen 66/512 from the Galana River, long. 39° 25′ E.

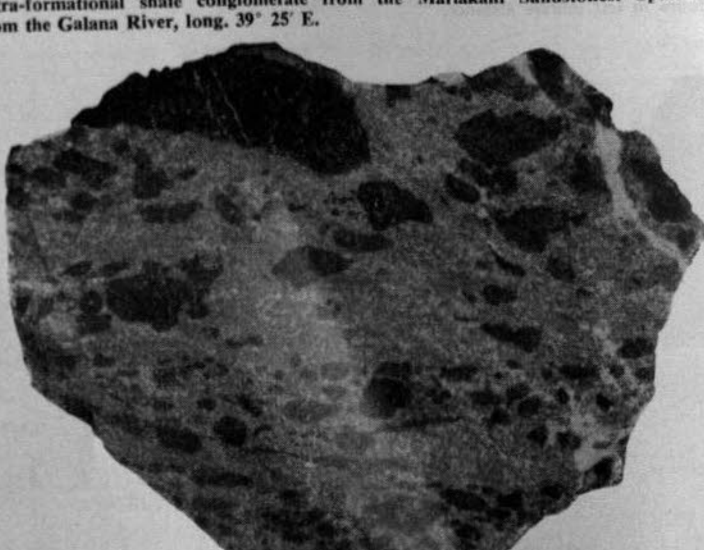

Fig. 2.—Intra-formational limestone breccia from upper division of the Taru Grits. Specimen 66/500, from one mile north-west of Sala.

PLATE III

Fig. 1.—Ripple-markings in the Maji ya Chumvi Beds, near Kuwetu.

Fig. 2.—Rectangular jointing in the Maji ya Chumvi Beds, near Kuwetu.

PLATE IV

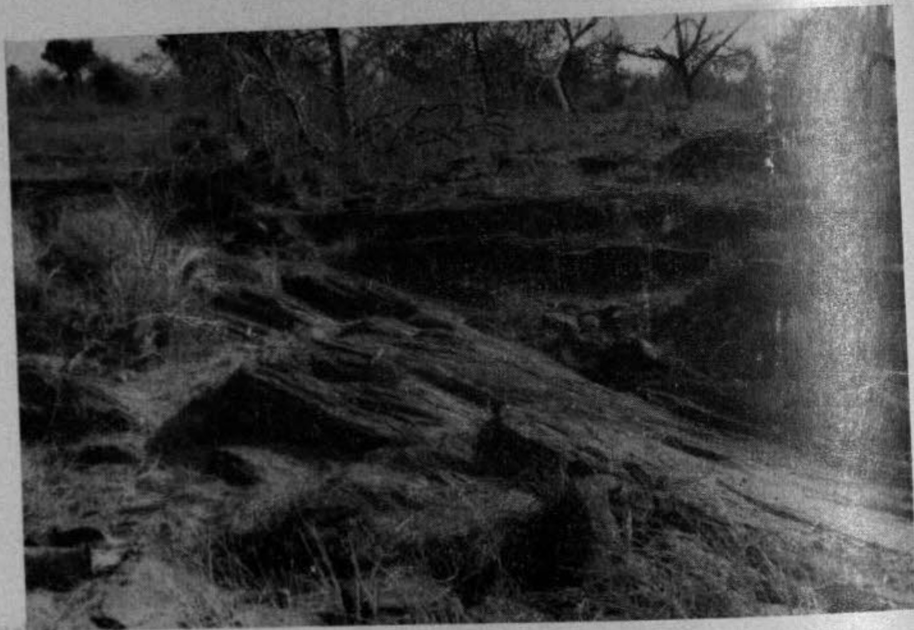

Fig. 1.—Local unconformity between the Taru Grits and the Maji ya Chumvi Beds. Kuwetu.

Fig. 2.—Unconformity between the upper Maji ya Chumvi shales and the Mariakani Sandstones. Divagu.

and produce few good exposures apart from those in the Galana river section where they contain thin black nodular limestone; they are relatively soft and friable and usually underlie topographically low plainlands between intervening low ridges formed by the more resistant sandstones or flags.

Where good sections are observable, as in the Galana south-east of Kuwetu, the beds are seen to be cyclical, like some of the shales in the Taru Grits (p. 17).. Each cycle varies between two and twenty feet in thickness, consisting of a brown fine-grained micaceous sandstone at the base followed by grey- or drab-coloured shales and siltstones with intercalations of black nodular or discontinuous limestone (Fig. 7). Cyclical deposition has long been recognized, for example in the Pennsylvanian coal measures, and the ideal series representing a maximum succession of deposits during a complete sedimentary cycle has been defined by Weller (1930). Such a "cyclothem" is rarely to be found fully developed in any one locality, but the observed partial cycles show that the various members could, under suitable conditions, occur in the ideal order. Thus the cycles in this part of the Duruma Sandstones contain, in appropriate sequence, three elements usually found in the lower terrestrial and fresh-water division of an ideal cyclothem. The underclays, coals, and marine shale with limestone which follow in an ideal sequence are apparently missing in the restricted sections examined, but it is possible that additional members of the cycle are present remote from outcrop, since sedimentary conditions might be expected to show a lateral variation over the width of the shelf on which deposition took place. The causes of cyclic sedimentation are uncertain, but amongst other explanations cyclothems in the Pennsylvanian of the eastern United States have been attributed to fluctuations in sea-level related to glacial episodes near the close of the Palaeozoic era (Wanless and Shepard, 1936, p. 1202), and it is possible that similar conditions applied during the deposition of the lower and middle Duruma Sandstones.

Immediately to the south of the Mid-Galana area the thickness and lithology of these beds has been determined with some accuracy from a borehole at Maji ya Chumvi, where some 3,600 ft. of shale and sandstone belonging to the series were penetrated before the Upper Taru grits were reached (Miller, 1952, p. 29). Since the bore-hole was not sited in the uppermost beds their total thickness in this section is likely to exceed 4,000 ft.

A two-fold division of the series is adopted in his report:—

(ii) *Upper shale and flagstone group* with *Estheria*. Marine neritic beds at base with *Eotriassic fish*.

(i) *Lower shale group*. Carbonaceous and micaceous shales with thin calcareous sandstones, and with *Palaeanodonta* beds and fresh-water limestone. *Voltzia* and *Ullmania* are present.

Shales of the lower part of the lower division are exposed in erosion gullies on the Mambrui–Kitui road north of Kuwetu (mile 83 from Mambrui), and also west of Sala airstrip where they occupy a broad syncline and have an outcrop some four miles in width from east to west. Here they are brown- and yellow-weathering, generally silty, and interbedded with carbonaceous laminated shales containing plant remains and thin black nodular limestones (Fig. 7). The frequent occurrence of rain-prints and mud-cracks shows that the lowermost Maji ya Chumvi beds were periodically

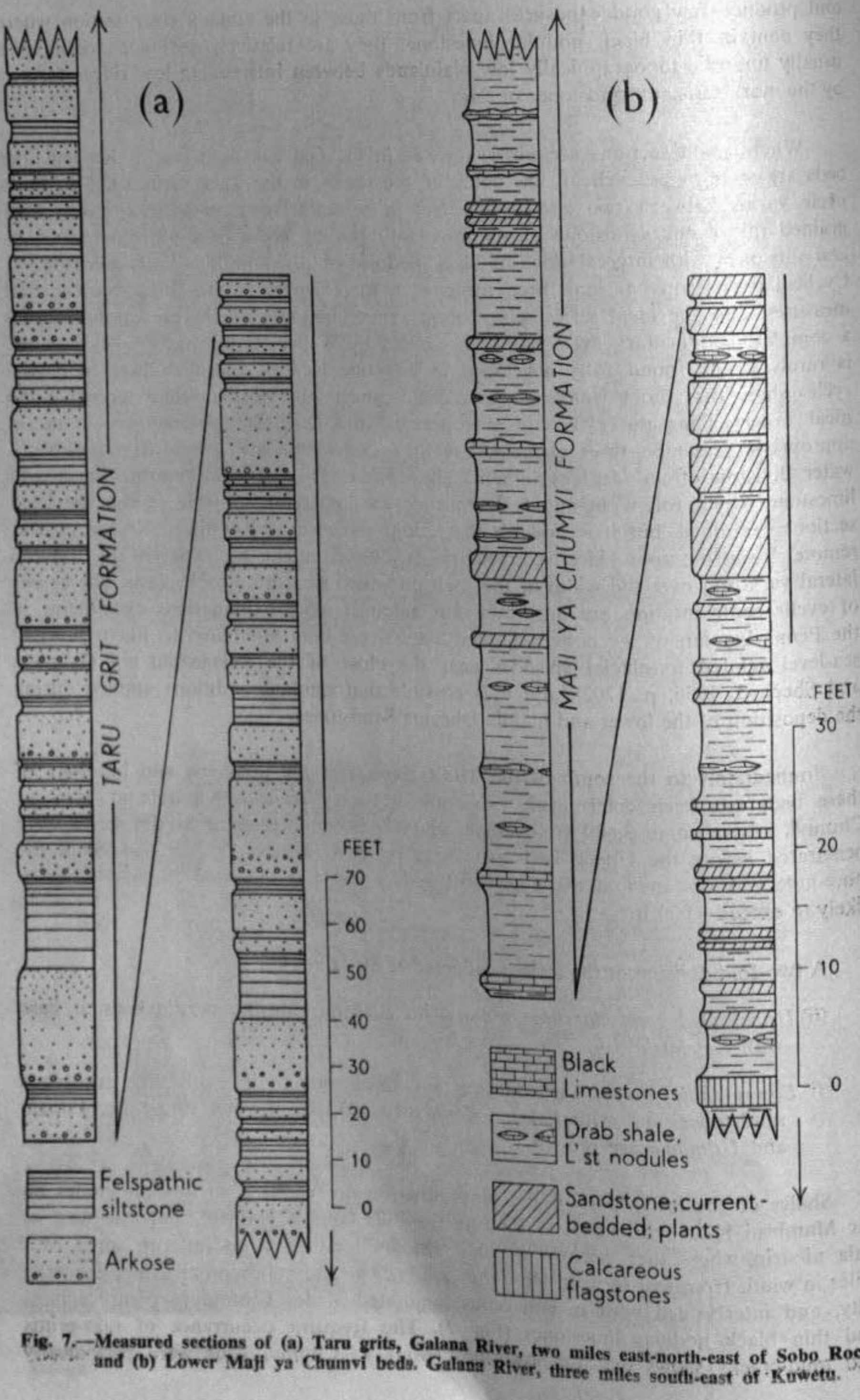

Fig. 7.—Measured sections of (a) Taru grits, Galana River, two miles east-north-east of Sobo Rock, and (b) Lower Maji ya Chumvi beds. Galana River, three miles south-east of Kuwetu.

exposed above water-level. The water had become shallower since lower Duruma times and occasionally retreated to expose the freshly deposited muds that were then dried and cracked. These retreats were probably followed by the evaporation of waters trapped in *playa* lakes, for the rocks often contain an appreciable percentage of precipitated salts, as is shown by the salinity of the ground-water obtained from them.

Specimens of the fresh-water bivalve *Palaeanodonta fischeri* Amal. were recovered from some of the uppermost beds of the Kuwetu syncline at a point approximately three miles west of Sala airstrip. Similar specimens together with fish-scales were first recorded from this area by Gregory (1921, p. 54), and later collections were made by McKinnon Wood (1938, p. 12). The fossils occur in a matrix of hard iron-rich and sandy shale reminiscent of the "mussel bands" of the British Coal Measures (*see* Weir in Mackinnon Wood, 1938, p. 12).

Elsewhere shales of the lower division occupy a belt extending from north-east of the Kulalu hills to Garbete in the south of the area. They are poorly exposed over a plain which is featureless apart from Kisusu hill, near the Garbete–Mapotea road. The hill is an isolated limestone knoll, or bioherm, oval in outcrop and unstratified. It is grey in colour and of fine to medium grain. Thin sections (specimens 66/450–452, 66/506) show patches of spongy algal deposits alternating with inorganic layers in delicate convex growths. Numerous cavities in the rock are filled with calcite. Scattered calcareous flags can be traced for some miles both to the north-west and to the south-east and possibly represent inter-reef deposits.

A representative specimen of limestone from Kisusu gave the following analysis:—

	Per cent
$CaCO_3$	95.00
$MgCO_3$	0.80
SiO_2	2.12

Analyst—Mrs. R. A. Inamdar.

The division between the upper and lower groups of the Maji ya Chumvi beds is arbitrary, but for convenience has been drawn at the base of a thin horizon of mudstones containing fossil fish-scales in cherty nodules. The nodules weather out of the host-rock and remain intermittently scattered on the surface in a narrow zone which extends northwards between Garbete and Mapotea. Similar fish remains were found by Miller (1952, p. 12) near the southern margin of the present area and were compared by Dr. E. I. White with the Eotriassic marine species *Boreosomus gillioti* (Priem) from Madagascar.

The shales above the fish band are micaceous or sandy and often contain dark iron-stained nodules in which numerous small branchiopods are preserved; they are well exposed for several hundred yards on the north bank of the Galana about a mile south-east of mile 67 on the Mambrui–Kitui road (Plate I, Fig. 2), where specimens of the Triassic *Estheria mangaliensis* Jones are abundant. This species is known from the Triassic rocks of India and also from the Série du Kwango (upper Trias) of the Belgian Congo (Furon 1950, p. 273). *Estheria* is characteristic of fresh or, more rarely, brackish water so that a return to a lacustrine environment is indicated. The shales are interbedded with thin sandstones in the upper part of the succession. These are typically pale brown, well-jointed, and often ripple-marked or current-bedded.

(*b*) *The Mariakani Sandstones*.—This arenaceous series outcrops along the eastern margin of the area where it rests unconformably on the upper division of the Maji ya Chumvi beds. It consists of massive current-bedded sandstones, fine-grained flaggy sandstones, and thin silty shales. The sandstones are characteristically poorly cemented, micaceous, and rather friable. In colour they are grey, green-grey, or yellow, but often weather brown. Many horizons exhibit a distinctive mottled appearance (cf. Caswell, 1956, p. 11), but this it not always seen in the lower members. Some exposures show cross-lamination and contortion of bedding planes, probably produced by slumping during compaction of the sediments. In thin section (specimen 66/511) the sandstones are seen to be composed of poorly sorted inequigranular sub-angular quartz and felspar grains. The minor constituents include sphene, garnet, epidote, diopside, zircon, apatite, ilmenite and carbonaceous material. Mica, usually muscovite, is a common constituent of both the sandstones and their thin shale intercalations; it is finely divided and occurs interstitially between the quartz and felspar grains where it makes a poor cementing material so that the weathered rock crumbles easily.

The lower beds of the Mariakani sandstones contain remarkable intra-formational breccias in which curved plates of shale and fragments of mudstone are included in a sandstone matrix (Plate II, Fig. 1). The argillaceous fragments were derived from the upper Maji ya Chumvi beds by localized erosion during the deposition of the lowermost Mariakani sandstones.

Strong lithological contrast between the upper Maji ya Chumvi beds and the lower Mariakani sandstones indicates that there was a break in sedimentation between the two series, but no marked angular unconformity is apparent and it is likely that the unconformity is restricted to local cut-and-fill features in the upper surface of Maji ya Chumvi beds which were temporarily exposed to erosion. The base of the sandstones can be seen in the Galana river at longitude 39° 22′ E. where cross-bedded conglomerates rest unconformably on north-easterly dipping shales of the upper Maji ya Chumvi beds (Plate IV, Fig. 2). The basal beds are coarse, micaceous, and brown or buff weathering, containing pebbles of grit, sandstone, shale, gneiss, and quartz. Characteristically mottled sandstones only appear a few hundred feet higher in the succession at about longitude 39° 23′ E. They are particularly well exposed over several hundred yards at a bend in the river about two miles south of mile 64 on the Mambrui–Kitui road, where massive to flaggy current-bedded mottled blue-grey sandstones have a mean dip of five degrees to the east.

That part of the series found within the Mid-Galana area is over 2,000 ft. in thickness. No fossils have been recovered here, and elsewhere only doubtful brachiopods (Thomson, Malindi area, 1956, p. 13) and unidentifiable plant remains have been reported (Caswell, Mombasa–Kwale area, 1953, p. 11).

(3) The Age and Correlation of the Duruma Sandstones

(a) Correlation with the Tanganyika and Madagascar Karroo

Like their counterpart in the Karroo sequences of south, central and east Africa, the Duruma Sandstones are composed of sedimentary formations yielding comparatively few fossils, and those that are found have a wide stratigraphical range. The succession, however, shows so marked a lithological similarity to the Permo-Triassic succession in Tanganyika and Madagascar, where fossil evidence is more detailed, that a general correlation and dating of the respective series can be advanced (*see* Table III, pp. 32-34).

The Taru Grits.—The only fossils recovered from the Taru grits in the Mid-Galana area are imperfectly preserved equisetaceous stems and pinnules, some of which are identifiable as *Schizoneura* sp., and large partly decorticated lycopod stems (Fig. 8). From a bore-hole in the uppermost Taru grits at Samburu railway station, south of the area mapped, the conifers *Voltzia* sp. and *Ullmania* sp. of Upper Permian to Rhaetic age were identified by Seward (Gregory, 1926, p. 83). Several years earlier

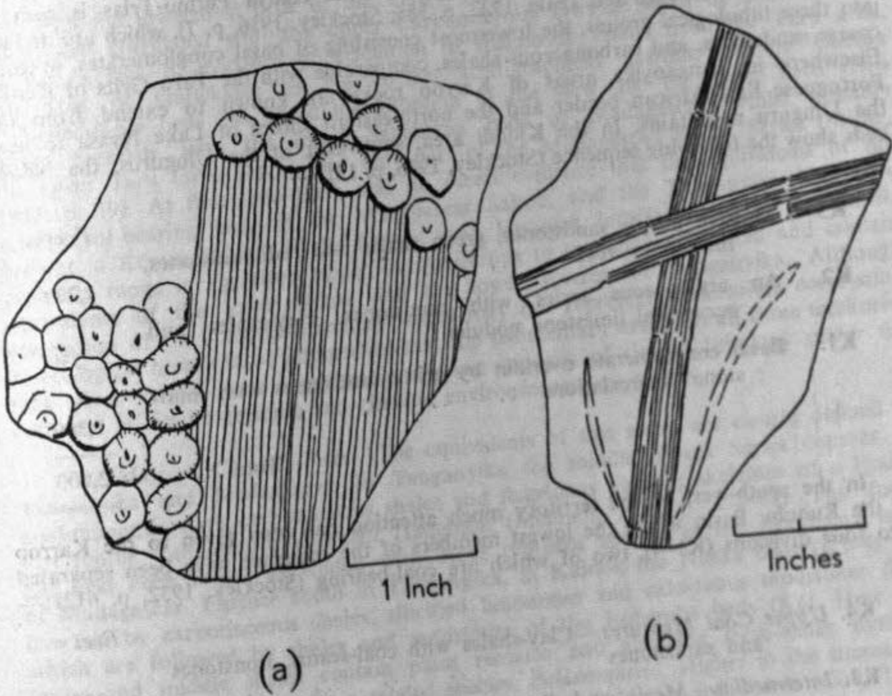

Fig. 8.—Fossil plants from the Taru grits.
(a) Stem of tree lycopod, specimen 66/513, from three miles south of Lali.
(b) *Equisetum* stems, specimen 66/514, from one mile south of Sala.

the fresh-water bivalve *Palaeanodonta fischeri* Amal. had been recovered from near the Galana river at approximately longitude 39° 9′ E. by Gregory (1921, p. 54), from shales that resemble those intercalated in the north-south-striking Taru grits on the railway near Taru hill and which, therefore, were considered to occupy a low horizon in the Duruma Sandstones. The restricted range of the species indicated an Upper Permian age for the beds. Mapping of the area demonstrates, however, that the *Palaeanodonta* shales outcrop near the axis of a northward-plunging syncline in a sequence correlated with the lower Maji ya Chumvi Beds. Beds at the same horizon do not appear in the type-section of the Taru Grit between Mackinnon Road and Samburu, although they may be located several miles further east in the region of Maji ya Chumvi. Furthermore, the *Palaeanodonta* beds in the Galana rest upon some 7,000 ft. of arkose, sandstones, and shales, comprising the entire Taru Grit formation, which is hence older than Upper Permian.

The presence of a basal tillite and large fossil lycopods low in the Taru Grits indicates that they range in age from Upper Carboniferous to Middle or early Upper Permian since (*a*) the several phases of the Dwyka Ice-age in South Africa, Madagascar, Peninsular India, Brazil, and Australia, commenced before the close of the Lower Carboniferous and had ceased by the earliest Permian (Du Toit, 1954, p. 56) and (*b*) tree lycopods, which were the dominant plants during the late Carboniferous and early Permian had become virtually extinct by the end of the Permian period.

In Tanganyika the southward extension of the Kenya Permo-Trias is seen in the Tanga beds (Seward and Teale, 1922, p. 385; Stockley, 1936, p. 7), which are divided into three lithological groups, the lowermost consisting of basal conglomerates, arkoses, coarse sandstones, and carbonaceous shales, comparable with the Taru Grits of Kenya. Elsewhere in Tanganyika areas of Karroo rocks are known to extend from the Portuguese East African border and the north-eastern shores of Lake Nyasa to near the Uluguru mountains. In the Kidodi area, south-east of the Ulugurus, the Ndeke beds show the following sequence (Stockley, 1936, p. 12):—

		Feet
K3–4.	Massive purple sandstones, green shales and red mudstones, limestones reefs	1,270
K2.	An argillaceous series with mudstones, clay-shales and occasional limestone nodules	330
K1.	Basal conglomerate overlain by gritty sandstones with mudstone intercalations	1,300
	Total ..	2,900

In the south-west of the territory much attention has been given to the Karroo of the Ruhuhu Basin where the lowest members of the sequence have been separated into four divisions (K1–4), two of which are coal-bearing (Stockley, 1932, p. 612):—

		Feet
K4.	*Upper Coal Measures.*—Clay-shales with coal-seams, ironstones and sandstones	335
K3.	*Intermediate Marls and Sandstones.*—Coarse gritty red and green sandstones and marls, and usually one limestone	450
K2.	*Lower Coal Measures.*—Gritty sandstones with coal-seams, carbonaceous shales and ironstones	450
K1.	Basal sandstones and conglomerate	1,690
	Total ..	2,925

This succession has been described in greater detail from the Ketewaka and Ngaka coalfields of the Ruhuhu basin by Harkin, McKinlay and Spence (1954). Spence (1950, p. 20) has described glacial varved clay-shales from the lowermost beds (K1) of the Ngaka area, whilst McKinlay (*op. cit.* 1954) records the calcareous nature of the Upper Coal Measures (K4).

In Madagascar the lowermost series of Karroo rocks, the Sokoa, has been divided into four groups (Besairie, 1946):—

4. Marine calcareous beds
3. *Serié rouge infèrieure*—a continental red sandstone and shale series
2. *Couches à charbon*—conglomerate, felspathic grits, carbonaceous shales and thin coals
1. Tillite and black interglacial shales.

The total thickness is approximately 2,700 ft. *Schizoneura* and *Glossopteris* have been recorded from the carbonaceous shales at Mavonono (Carpentier, 1935, p. 8).

Both the lowermost beds of the Tanganyika Karroo and the Madagascar Sakoa have been correlated with the upper Carboniferous Dwyka Series of South Africa. In Kenya lack of evidence of glaciation or diagnostic fossils from the Taru grits, and lack of knowledge of the correct stratigraphical position of the Galana *Palaeanodonta* beds has urged the adoption of the view that the upper Taru Grits might correlate with the lower Sakamena beds of Madagascar, whilst possibly the lower Taru Grits represented only part of the Madagascan Sakoa Series (Miller, 1952, p. 19). At that time there was no direct evidence that the equivalents of the lower coal-bearing beds of the Madagascar Sakoa, and the Tanganyika K2, were present in Kenya. Survey of the present area, however, indicates that the Taru Grits probably range in age from upper Carboniferous to the middle Permian and contain equivalents of the lower Sakoa and the lower Karroo of Tanganyika. Although correlation of the main sedimentary stages may not represent an absolute correlation in geological time it is of importance that the sedimentary events in all three territories took place in the same sequence, producing deposits of similar lithology under the influence of similar tectonic and climatic environments (*see* p. 35).

The Maji ya Chumvi Beds.—The equivalents of this series are clearly defined in Tanganyika and Madagascar. In Tanganyika the middle Tanga Series consists of predominantly dark carbonaceous shales and flagstones yielding skeletons of a lizard-like reptile *Tangasaurus mennelli* Haughton (Mennell, 1930, p. 278–81). This fossil has also been found associated with other reptilian species in the Sakamena beds of Madagascar. Further south in Tanganyika, at Kidodi, the Ndeke beds (K1–4) are overlain by carbonaceous shales, silicified limestones and calcareous sandstones (K5) which are followed by shales and sandstones of the Ruhembe beds (K6). Here the lower and middle shales contain plant remains and also the fresh-water mollusc *Palaeanodonta,* together with a related species, *Palaeomutela.* Higher in the succession there are marine beds with *Gervillia, Myalina, Modiolopsis,* and *Pteria* (Cox, 1936, p. 37). The fresh-water and marine phases, therefore, occur in the same order and in similar lithofacies in both the Kidodi and Mid-Galana areas. In the Ruhuhu basin the marine incursion is apparently absent, the Ruhuhu beds (K5) consisting of mudstones, siltstones, fine-grained sandstones, limestone bands, and fresh-water shales with *Palaeomutela,* which are followed by mudstones and sandstones containing reptilian bones (K6).

The Madagascan Sakoa is followed by the Sakamena group, a series of dark plant-bearing shales and flagstones having a basal conglomerate and yielding a rich xerophytic flora and reptilian remains. There are also marine beds with fossil fish including *Colobodus, Semionotis,* and *Atherstonia,* and in the north corals and ammonites. The upper shales contain *Estheria.*

Thus the fresh-water shales containing carbonicola-like shells and the marine and reptilian beds occurring in the middle Karroo of East Africa and Madagascar allow this part of the system to be dated with fair accuracy over a wide province. The Galana *Palaeanodonta* beds are of Upper Permian age, as are the *Palaeanodonta-Palaeomutela* horizons of the lower Ruhuhu and Ruhembe beds of Tanganyika. The marine lamellibranch fauna of the Madagascan Sakamena and the Kidodi upper Ruhembe beds belongs to the uppermost Permian or basal Triassic—probably the former according to Cox (1936, p. 33), whilst the fossil Palaeoniscid fish found in Kenya, Tanganyika and Madagascar, are early Triassic forms. The marine incursion in Kenya, east-central Tanganyika, and Madagascar, therefore, marks the close of the Permian and beginning of the Triassic period. A correlation of the Karroo formations in Kenya, Tanganyika and Madagascar is given in Table III.

TABLE III.—CORRELATION, LITHOLOGY AND STRATIGRAPHY OF THE PERMO-TRIASSIC FORMATIONS OF KENYA, TANGANYIKA AND MADAGASCAR

Period	S. Africa	KENYA		Climate
		Thickness	Mid-Galana area	
L. Jurassic (?) .. / Triassic	U. Beaufort	*ft.* 2,500	Mariakani Sandstones Grey, mottled, current-bedded, micaceous, poorly cemented sandstones. Unfossiliferous. Basal conglomerate with shale galls.	Warm and humid.
Triassic	M. Beaufort	2,800	Upper Maji ya Chumvi Beds Thin sandstones and calcareous siltstones, flagstones, shales with fossiliferous nodules—*Estheria*. Shales with fossil fish—*Boreosomus*?	Warm and semi-arid.
Permian	L. Beaufort	2,000	Lower Maji ya Chumvi Beds *Palaeanodonta* beds. *Carbonaceous* laminated shales, siltstones, thin calcareous sandstones, limestones. Fossil plants—*Voltzia, Ullmania.* Local unconformity.	Warm increasing aridity. Warm and humid.
Permian	Ecca	500 2,000–3,000	Taru Grits Sandstones, black limestones, oolitic limestones, calcareous flags. Massive, red, coarse current-bedded felspathic sandstones, green sandstones, conglomerates, mudstones, calcareous sandstones. Probable unconformity.	Warm and semi-arid with intermittent temperate periods. Temperate with heavy precipitation.
Carboniferous ..	Dwyka	1,000–4,000 100–200	Arkoses, grits, concretionary sandstones, carbonaceous shales, coalified plant remains, ironstone lenticles. Conglomerates, tillite, varved shales, shales.	Glacial and interglacial. Cold. Semi-arid, intermittently humid.
Archaean (?) ..			Crystalline gneisses and schists.	

TABLE III.—(*Contd.*)

Period	S. Africa	Sub-division	Thickness	TANGANYIKA: Songea (Stockley, 1952, McKinlay, 1951, Spence, 1951)	Thickness	Kidodi (Stockley, 1936)	Climate
L. JURASSIC (?)	U. BEAUFORT	K7	*ft.* 1,200	KINGORI SANDSTONE Coarse current-bedded grits, sandstones and conglomerates.	*ft.* 3,000	Conglomeratic sandstones with alternating calcareous shales.	Warm and humid.
TRIASSIC ..	M. BEAUFORT	K6	300	LOWER BONE BED Green and grey mudstones, sandstones, limestone nodules. Reptilian bones. Fossil wood.	250	RUHEMBE BEDS Sandstones and carbonaceous shales. Marine beds. *Gervillia, Myalina, Modiolopsis, Pteria.*	Warm and semi-arid.
PERMIAN	L. BEAUFORT	K5	700–1,000	RUHUHU BEDS *Palaeomutela* beds. Fine-grained sandstones, mudstones, shales, *calcareous throughout*. Magnesian limestone beds and nodules. Rare fossil wood (*Dadoxylon*) and *Glossopteris*.	700–1,000	*Palaeanodonta-Palaeomutela* beds. *Carbonaceous* and bituminous shales, calcareous sandstones, unfossiliferous limestones. Fossil plants—*Glossopteris*.	Warm increasing aridity. Warm and humid.
	ECCA	K4	300	UPPER COAL MEASURES Sandstones, carbonaceous shales, calcareous beds.	1,600	NDEKE BEDS Reefs and nodules of limestone.	Warm and semi-arid with intermittent temperate periods.
		K3	600–700	INTERMEDIATE SANDSTONES AND MARLS Massive, red, coarse, current-bedded felspathic sandstones, conglomerates, mudstones, calcareous sandstones.		Massive purple sandstones, red mudstones, green shales and mudstones. Mollusc—*Kidodia stockleyi*.	Temperate with heavy precipitation.
CARBONIFEROUS ..	DWYKA	K2	400–600	LOWER COAL MEASURES Arkoses, grits, concretionary sandstones, carbonaceous shales, coals, ironstone lenticles.	1,300	Gritty sandstones, conglomeratic at base. Red mudstone intercalations.	Glacial and interglacial. Cold. Semi-arid, intermittently humid.
		K1	250–500	BASAL CONGLOMERATE AND SANDSTONE Conglomerate, varved shales, shales.			
ARCHAEAN(?)				Crystalline gneisses and schists.			

(*Continued on page 34*)

TABLE III.—(*Contd.*)

Period	S. Africa	Madagascar: Thickness	Madagascar: Besairie, 1946, 1948	Climate
		ft.		
L. Jurassic (?) .. / Triassic	U. Beaufort	600–3,000	ISALO I Conglomeratic, current-bedded, poorly cemented grits and sandstones. Unfossiliferous.	Warm and humid.
Triassic	M. Beaufort	300–900	SAKAMENA, UPPER RED SERIES Red, green, grey, current-bedded, unfossiliferous sandstones.	Warm and semi-arid.
Permian	L. Beaufort	600–3,000	SAKAMENA, SANDSTONE-SHALE SERIES Flagstones, mudstones, nodular shales. Fossil fish—*Atherstonia, Semionotus, Colobodus.* Micaceous flagstones, carbonaceous beds (S. of C. St. Andre). Reptiles—*Tangasaurus, Hovasaurus.*	Warm increasing aridity.
		100–250	Plants—*Glossopteris* at base—xerophytes above. Basal conglomerate.	Warm and humid.
	Ecca	1,000–3,000	SAKOA Marine calcareous beds (Vohitolia and Lanapera)—*Productus, Spirifer, Cyathophyllum.*	Warm and semi-arid with intermittent temperate periods.
			LOWER RED SERIES Massive red sandstones, green sandstones, micaceous sandstones. Silicified wood and *Glossopteris.*	Temperate with heavy precipitation.
Carboniferous ..	Dwyka	150–600	COAL BEDS Arkoses, grits, carbonaceous and micaceous shales, coals, ironstone lenticles. *Glossopteris.*	Glacial and interglacial. Cold. Semi-arid, intermittently humid.
		300	Conglomerate, black shales, tillite.	
Archaean (?) ..			Crystalline gneisses and schists.	

(b) Correlation with the South African Karroo

The South African Karroo sequence has provided a standard for correlation of the Karroo of East and Central Africa. The Dwyka tillite and shales of Upper Carboniferous age are overlain by the Ecca Series, divided into three divisions with a lower and upper shale group, and a middle grit and sandstone group containing workable coals. In some areas the lower division and parts of the middle division are missing (Du Toit, 1954, p. 284). The Ecca coals appear to have been formed in place over much of Natal and the Transvaal, but some of the slightly later coals of the Northern Transvaal and Rhodesia seem to represent accumulations of drifted vegetable matter. The upper Ecca shales contain the fossil fish *Acrolepis*. Fossil plants include *Glossopteris, Gangamopteris,* and several lycopod species.

The Beaufort Series, which follows the Ecca and in its lower part contains the Upper Permian fossils *Palaeanodonta* and *Palaeomutela*, and fossil fish *Acrolepis* and *Atherstonia*, has been divided into six vertebrate zones. The upper limit of the Lower Beaufort (top of the Permian) is marked by the *Cistecephalus* zone. In Madagascar a lamellibranch horizon with *Gervillia* and *Modiolopsis*, which marks an early marine transgression in the Sakamena, is surmounted by beds containing the amphibian *Rhinesuchus* cf. *senekalensis* which is referred by Piveteau (1926, p. 100) to the *Cistecephalus* zone of the Lower Beaufort, and by Haughton (1925, p. 230) to the immediately higher *Lystrosaurus* zone of the Middle Beaufort. It appears likely, therefore, that the marine beds in the middle of the Maji ya Chumvi series can be correlated with the lowermost Middle Beaufort, and the remainder of the upper Maji ya Chumvi Beds and the Mariakani Sandstones with the Middle and Upper Beaufort Series.

The South African Karroo divisions are shown on Table III.

(4) The Depositional Environment of the Lower and Middle Duruma Sandstones

Sedimentation of the unmetamorphosed rocks of the area began in the Upper Carboniferous period. The tillite exposed west of the Lali hills on the surface of a faulted block of metamorphic rocks represents part of the ground moraine deposited by a Gondwanaland ice-sheet which probably had its centre near the Tropic of Capricorn. From centres on the tropic ice extended southwards beyond the southern tip of Africa and northwards to the present-day Equator. The northernmost deposits of this glacial period have been recorded in the Belgian Congo at about latitude 1° 00′ S. and they probably extend to 1° 00′ N. (Horneman, 1913). Part of the Dwyka record preserved in the Congo shows two ice advances with an interglacial period (Veatch, 1935, p. 162), and it is likely that the northern limits of at least one of these glaciations also reached Kenya. The Mid-Galana tillite appears to have been deposited on an uneven floor and only preserved in pockets beneath subsequent sediments. It is bleached to a pale grey colour as a result of exposure to weathering after withdrawal of the ice.

A period of post-orogenic terrestrial sedimentation followed, opening with the desposition of arkoses and fanglomerates which are thickest near their source in the west and thin towards the east. In the Galana section indicated dips, if continued in depth, would imply a thickness of some 25,000 ft. of coarse clastics and intercalated siltstones. It is apparent, however, that the surface dips of the cross-bedded arkoses and felspathic grits are depositional and reduce in depth with an attendant thinning of individual beds. The fluvial deposits are conspicuous for the coarseness and angularity of their constituents, and the high proportion of felspar, which often exceeds 30 per cent of the rock. The tectonic factors influencing this type of deposit have been emphasized by Krynine (1941, p. 1918). Thick arkose is commonly developed at the fringe of a granitic or metamorphic terrain having steep youthful topography as a result of uplift and block-faulting at the end of an orogenic cycle. The arkoses of the Taru Grits were derived from the Basement System by violent erosion of the crystalline rocks and rapid burial of the resulting ill-sorted *débris*. It is likely that some graded arkose was deposited in lakes of tectonic origin. During this period rainfall was probably heavy (more than 50 in. per annum), and temperatures low.

With greater distance from the source, the thick torrential arkoses thin laterally into cold flood-plain and swamp deposits represented by silty shales, and carbonaceous shales which are intercalated in the lower Taru Grits with increasing upward frequency. At this stage the wasting crystalline rocks had been lowered by erosion and supplied materials of finer grain. Extensive bodies of shallow fresh or brackish standing water and low wet ground supported abundant plant life, producing accumulations of vegetable *débris* which were buried by periodic influxes of silt and mud. At this stage deposition assumed a cyclical character (*see* p. 16) under fluvial and deltaic conditions, and it is assumed that the regular variations of lithology found in the cyclothems arose as the result of changes of base-level during the final fluctuations of the retreat of the Gandwana ice-cap.

The presence of a thick series of red grits and sandstones in the upper Taru Grits indicates that the climate was becoming warmer and drier in the Lower Permian period. Oolitic limestones and lime-muds were deposited in agitated waters during the next stage and may be contemporaneous with the limestones of the first marine transgression in the Madagascan Sakoa series, but in the absence of marine fossils they can only be attributed to a fresh-water origin.

The ripple-marked shales and siltstones of the lower Maji ya Chumvi Beds were laid down in shallow waters which occasionally retreated exposing the freshly deposited muds and silts. Plant life was abundant and probably flourished in deltaic areas fringing large fresh-water lakes. At the end of the Permian and during the early Triassic period the lowlands were flooded by shallow seas in which thin limestones were deposited. At this stage the northern Madagascan seas were warm and supported corals and ammonites, whilst the contemporaneous continental flora contained an increasing variety of xerophytic plants indicating a relatively dry climate. Withdrawal of the sea from eastern Kenya was followed by a further period of deltaic and lagoonal conditions during the deposition of the upper Maji ya Chumvi shales.

The Mariakani Sandstones, following the Maji ya Chumvi shales after a period of erosion, were laid down in a fluviatile environment during the upper Triassic period. They indicate a marked change in depositional and climatic conditions. Their coarse clastic constituents, decomposed felspar grains, cross-bedding, and thickness of individual beds, imply strong erosion of the source rocks with abundant precipitation in a warm climate.

3. Post-Miocene Beds

Yellow and brown coarse poorly consolidated cross-bedded sandstones can be seen at several points in the Galana river, where they rest unconformably on outcrops of the Duruma Sandstones. They are well exposed on the south bank of the Galana at longitude 39° 4′ E. These beds often contain an abundance of phonolite pebbles similar in composition to the Yatta plateau phonolite of Miocene age which covers an extensive area to the east and north-east of this part of the Galana valley.

4. Superficial Deposits

Superficial accumulations over the flat Mid-Galana plains are generally thin and may be classified into three types:—

(1) Red sandy lateritic soils.

(2) Maroon kaolinitic soils.

(3) Grey acid soils.

(1) Red Sandy Lateritic Soils

The red soils mask the deeply decomposed gneisses and schists of the Basement System. They contain a high proportion of quartz gravel and sand, cemented by a red lateritic crust. The heavy minerals derived from the underlying crystalline rocks have suffered little transportation so that ilmenite, magnetite, and garnet are common in the top soils, and mica is liberally distributed over the mica schists and pegmatites.

(2) Maroon Kaolin Soils

The gently dipping or horizontally disposed sandstones are less deeply decomposed than the steeper-dipping rocks of the Basement System, and give rise to a soil mantle which is often maroon or mauve-red in colour, dusty and comparatively gravel-free. Magnetite and garnet are not so abundant as over the metamorphic rocks. The basal arkose of the Taru grits is generally covered by yellow-brown kaolinitic soils. The felspar of the arkose remains fresh until it is released from the rock during weathering, when it rapidly breaks down into kaolin minerals. On account of their lack of depth the soils over the sandstones support rather less vegetation than the soils over the metamorphic rocks.

(3) Grey Acid Soils

Dark heavy clay soils have accumulated on the flat poorly drained plains in the centre and east of the area. They are localized in belts underlain by argillaceous bedrock and support less vegetation than either of the two preceding soil types. They give rise to dusty, grass-covered, open savannah country.

At the margins of the Galana river the alluvial strip is very narrow. The sands and gravels form cross-bedded natural levees in the west and central parts of the area, but in the east the river approaches grade and is bordered by wide scrolls of fine sand and silt.

5. Igneous Rocks

A dark green lamprophyre dyke emplaced in sandstones and shales on the south bank of the Galana river at longitude 39° 4′ E. was the only igneous rock observed *in situ* in the area. It is from three to four feet in width, shows chilled margins, and contains visible green to black phenocrysts. In thin section (specimen 66/514) the phenocrysts are seen to consist of a dark brown pleochroic barkevikite and a green augite, enmeshed in a pilotaxitic matrix of andesine, barkevikite, serpentine, and zeolites. Iron ore granules and needles of apatite are scattered throughout the groundmass. The lamprophyre can be classified as a camptonite.

A loose block of fine-grained igneous rock was noted near a water-hole immediately west of the Kulalu hills. A thin section (specimen 66/476) shows that it consists of small euhedral phenocrysts of fresh olivine, phenocrysts and glomero-porphyritic groups of andesine, and rare porphyritic augite, embedded in a trachytic groundmass composed of andesine laths and augite granules, with a dusty base. This rock is probably related to the basanites, olivine-nephelinites, and trachybasalts recorded by McKinnon Wood (1938, p. 112), and Thompson (1956, p. 38) from the Sabaki valley to the east of the area mapped. It was probably derived from a dyke which was not observed in the field.

VI—STRUCTURE AND TECTONICS

The main structural elements of the area are (Fig. 9):—

(*a*) A wedge-shaped faulted block of metamorphic rocks, measuring about six miles from west to east in the Galana river and narrowing southwards.

(*b*) A northward-plunging syncline of Taru Grits and lower Maji ya Chumvi Beds lying to the west of the fault block and occupying the north-western part of the area.

(*c*) A broad eastward-dipping belt of middle Duruma Sandstones in the east.

The exposed metamorphic rocks have the N.N.W. strike-trend of the Mozambiquian belt and a westerly foliation dip. In the Galana section, between Sala and the Lali hills unusually low dips of between 20° and 40° were recorded. They are steepest at the western margin of the metamorphic inlier near Sala. This structural disposition of the gneisses is noteworthy since the Basement System rocks to the west of the area exhibit uniformly high dips in a belt of similar trend extending through Voi, Tsavo, and Mtito Andei. South of Sala Rock the gneisses show evidence of ancient shearing, containing flaser-gneisses, and mobilized limestones in a zone parallel to the later boundary faults between the Basement System and Duruma Sandstones.

Two large linear outcrops of crystalline limestone, one of which forms Kulalu in the centre of the area, are of similar thickness and show a southward strike convergence attended by a reduction in dip and broadening of their respective outcrops, so that they appear to be the limbs of an isoclinal syncline having a gentle northerly plunge. Elsewhere there are no suitable marker horizons to indicate whether the metamorphic sequence consists of closely-packed isoclinal folds or a straight succession.

The Duruma Sandstones in the north-west have been let down into the metamorphic rocks by a series of normal faults. The fault pattern has been influenced by the strike of the underlying basement, most of the fractures having a north or N.N.W. trend. The metamorphic block in the centre of the area is essentially the remains of a horst to the west of which the Karroo sedimentary rocks occupy a complementary structural trough. In the Galana river, between the western margin of the area and longitude 39° 8′ E., the sedimentary beds dip to the east or north-east. Near Kuwetu they become horizontal and between there and Sala dip to the west. The syncline is asymmetrical, the eastern limb forming a broad drag-zone in which the regional easterly dip of the Duruma Sandstones has been reversed at the western margin of the Sala horst. The sandstones and shales are traversed by normal faults which are accompanied by brecciation, minor drag effects, iron and manganese-staining, and calcite veining. Many of the smaller fractures are antithetic normal faults complementary to the main horst and graben dislocations.

The principle faults can be followed over the plains to the south and north of the Galana river. The Duruma Sandstones are generally of low dip except in the proximity of faults, where dips increase sharply and there is more outcrop than usual. Breccia and sometimes slickensided grit and crystalline rock, is scattered on the surface. Kunkar limestone concretions are thicker over the fault-planes, producing light-coloured patterns in the top soil which are visible in air photographs. South of the Voi–Sala road the contact between the Basement System and Taru grit is determined by several parallel faults indicated by low ridge features and lines of white anthills which show a remarkable linear distribution among their red neighbours.

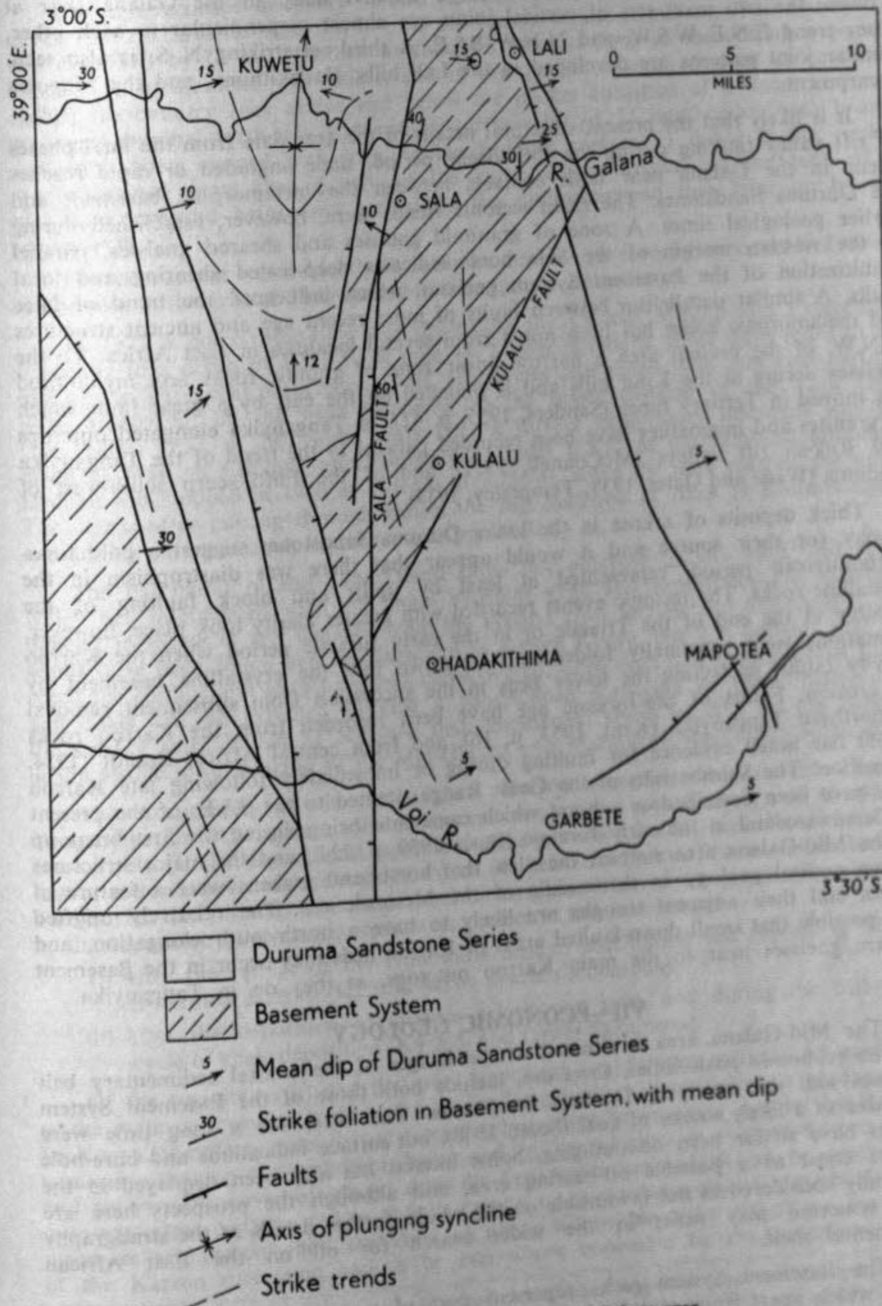

Fig. 9.—Structural map of the Mid-Galana area.

Jointing is well shown throughout the area, particularly in the flagstones and medium-grained sandstones of the Maji ya Chumvi Beds. In the Galana river at Kuwetu the two main sets of vertical joints are almost perpendicular to each other. They trend E.N.E.-W.S.W. and N.N.W.-S.S.E. A third set striking N.-S. is also seen. Similar joint patterns are developed in the Lali hills, Hadakithima, and the Mapotea escarpment.

It is likely that the present structural details of the area date from the final phases of rift valley faulting during the Pleistocene period, since ungraded or rapid reaches occur in the Galana near fault contacts between the metamorphic basement and the Duruma Sandstones. The main tectonic trends were, however, established during earlier geological times. A zone of granitoid gneisses and sheared gneisses, parallel to the western margin of the Sala horst indicates deep-seated shearing and local granitization of the Basement System gneisses, which influenced the trend of later faults. A similar parallelism between faults of more recent age and ancient structures and metamorphic zones has been noted from several localities in East Africa. To the N.N.W. of the present area a narrow linear zone of granitic rocks and mylonitized gneisses occurs in the Kitui hills and is bounded on the east by a great fault which has moved in Tertiary times (Sanders, 1955, p. 41). In Tanganyika elongated outcrops of granites and migmatites have been recorded parallel to the trend of the Tanganyika and Rukwa rift valleys (McConnell, 1951), and of the Fufu scarp south-west of Dodoma (Wade and Oates, 1938; Temperley, 1938).

Thick deposits of arkose in the lower Duruma Sandstones suggest a bold topography for their source and it would appear that there was diastrophism in the Carboniferous period, represented at least by uplift and block faulting of the crystalline rocks. The tectonic events recorded with greater clarity took place, however, possibly at the end of the Triassic or in the early Jurassic period when the Karroo formations were synclinally folded and let down into the crystalline basement by gravity faults, protecting the lower beds in the succession from subsequent removal by erosion. Faults of pre-Jurassic age have been recorded from the Karroo rocks of northern Tanganyika (Kent, 1953, p. 16), and from central Africa, Brandt (1954, p. 68) has noted evidence for faulting during or immediately following late Karroo deposition. The Shimba hills of the Coast Range situated to the S.S.E. of the present area have been described as a horst which came into being during the first break-up of Gondwanaland in the early Jurassic (Busk, 1939, p. 224), and the major structures of the Mid-Galana area support the view that horsts and grabens were a feature of Kenya coastal geology in the middle of the Mesozoic era. The relatively uplifted blocks and their adjacent troughs are likely to have a north-south elongation, and it is possible that small down-faulted areas of Karroo beds may occur in the Basement System gneisses near to the main Karroo outcrops, as they do in Tanganyika.

VII—ECONOMIC GEOLOGY

The Mid-Galana area is situated at the fringes of the coastal sedimentary belt and its economic possibilities, therefore, include both those of the Basement System gneisses and the overlying Duruma Sandstones. The latter for a long time were regarded as a likely source of coal (Scott, 1948), but surface indications and bore-hole results have so far been discouraging. Some interest has also been displayed in the Kenya coast as a possible oil-bearing area, and although the prospects here are generally considered as not favourable on the whole, further details of the stratigraphy and structure may assist in the wider search for oil on the East African continental shelf.

The Basement System rocks represent part of a metamorphosed sedimentary series which apart from contained pegmatites shows no evidence of granitic intrusion accompanied by mineralization. The only minerals of possible economic importance are those which have been formed during regional metamorphism.

1. Coal

The first recorded discovery of coal from the Karroo of Kenya was to the south of the present area at mile 53/14* on the Kenya-Uganda Railway. The occurrence was described by C. W. Hobley† as follows: "In the floor of the cutting a pocket about 2 ft. in diameter was visible, and in this pocket a small amount of coal was visible, the country rock above and below the pocket consisted of a dense compact grey grit dipping north-east and with a surface dip of 5° interbedded with brown and grey shales stained with iron on the bedding surfaces. I doubt if the pocket ever contained more than ½ cwt. of the carbonaceous matter but the bulk of it had been removed before my arrival by the discoverer and then later on by the Indian P.W.I.".

This occurrence was evidently at a similar horizon to a very thin coaly bed which can be seen in the grits of Taru quarry to the south of the railway.

In 1927 a cored bore-hole was drilled by the Coastal Mining and Exploration Company to a depth of 1,338 ft. at mile 44/2, near Samburu, some eight miles to the east of the Taru coal occurrence. Grits, sandstones and shales with thin coal partings were penetrated, all the beds belonging to the upper division of the Taru Grits (*see* Miller, 1952, p. 28). Some years later a further exploratory bore-hole was put down at Maji ya Chumvi, approximately 11 miles E.S.E. of the Samburu bore-hole. Drilling was stopped in 1950 at a depth of 3,736 ft. when the bore reached the upper Taru Grits after passing through almost the full thickness of Maji ya Chumvi shales and finding only thin coaly layers (*op cit.*, pp. 29–31).

The flat plains of the Taru Desert show few outcrops of any kind, and shales which are intercalated with the more resistant grits and sandstones are extremely difficult to locate at any distance from the Galana river section. No outcropping coal seams have been found here or elsewhere in eastern Kenya, but it is unlikely that any reach the surface and have remained undiscovered, since even thin carbonaceous shales and coals can be expected to give a conspicuous scattering of black material in the surface soils. It can be accepted that commercial seams of coal do not outcrop in the visible lower Karroo of the Mid-Galana and Mariakani–Mackinnon Road areas.

The stratigraphy of the Mid-Galana Karroo compares closely with that of Tanganyika and Madagascar where economic coals have been located, and as appears from Table III the depositional conditions were generally similar, with local variations due to tectonic environment and the extent of the sea in Permo-Triassic times. In both Tanganyika and Madagascar local coal-forming conditions (not necessarily attended by the deposition of economic coals) were present at two main stages:—

(i) After the retreat of the Gondwana ice-cap and during the deposition of the lowermost Karroo (K2, and Sakoa *couches à charbon*).

(ii) After the deposition of tectonic arkose and grits, and during the following cycle of shale deposition (K4–K5, and Lower Sakamena).

Of the two stages (i) was the more important coal-forming period and gave rise to the main commercial coals of Songea in Tanganyika and of Tulear in Madagascar. In Kenya, therefore, potential coal-bearing beds may be expected low in the Karroo succession, having a distribution determined by irregularities in the pre-Karroo floor and its variable cover of glacial deposits. Coal-seams are unlikely to be continuous over any great distance and to thin or fade out against fluvio-glacial barriers. If coal measures are present they are likely to occur within less than 300 ft. of the base of the Karroo succession and to be everywhere concealed by the boundary faults

* Mileages on the railway are measured from Mombasa. Intermediate mileages are quoted, for example 32/5, the figure after the stroke representing the number of sixteenths of a mile beyond mile 32.

†Report dated August 14, 1911, filed (M213/II) in the Mines and Geological Department.

between the Duruma Sandstones and the Basement System gneisses. Evidence for this faulting can be seen in the sudden increase in dip of the sedimentary beds close to their contacts with the Basement System, where cleavage, shattering, veining, and slicken siding of the wall-rocks is common. The boundary faults are not necessarily straight, in fact some show sharp variations in strike in both the Mid-Galana and Mariakani–Mackinnon Road areas. Gentle rolls, arches and synclines in the adjacent strata are related to the irregularities of the fracture trends.

In Tanganyika almost all the main Karroo areas are bounded by faults. Unfortunately in Kenya the known Karroo outcrops are found in the flat eastern plains or Nyika, where there are few good sections, in contrast to some Karroo areas of Tanganyika in which the faults and downthrown coal-measures are revealed by deep dissection. It is likely that coal indications so far obtained in Kenya have come either from horizons equivalent to the K4–K5 of Tanganyika (in which few commercial seams occur), or from fragmentary material included in the lower Taru Grits, which may have been derived from *previously deposited carbonaceous beds* that do not outcrop.

Of the bore-holes so far drilled in search of coal, that at Samburu (Coastal Mining and Exploration Co. Ltd.) was stopped at a depth some 2,000 ft. short of any likely coal-bearing horizon, and the deepest level reached at Maji ya Chumvi was possibly 3,000 ft. above the Karroo basal beds. A minimum depth to the lowermost Karroo is most likely to be found near the western boundary faults at the outcrops of the lowest visible part of the succession.

The basal beds may not, however, contain suitable seams in this zone of minimum depth, because depressions in which coal could accumulate during upper Carboniferous or lower Permian times may not have existed so far west in the Karroo basin. If such depressions exist they may be situated at some distance to the east of the inland faulted margins of the Duruma Sandstones. In this case coal-bearing horizons could only occur beneath a deep cover of Karroo beds. In order to search for any depressions which are not situated at prohibitive depths it is necessary first to obtain more sub-surface information concerning the configuration and depth of the pre-Karroo floor. If sub-surface methods finally establish that the faults bounding Karroo outcrops generally have throws exceeding 100 ft. and that the unconformity between the Basement System and lower Karroo shows structural lows at depths of less than 4,000 ft. it is considered that the latter would repay exploratory boring. It should be borne in mind, however, that although coal-forming conditions may have applied during the deposition of the lowermost Karroo beds, the seams formed may be too impure or thin to be workable. In Tanganyika no seams of *commercial quality* have been found north of the Lake Nyasa coalfields and in Madagascar, workable seams are only found in the south of the island. In Southern Rhodesia the lower Karroo of the Mid-Zambesi has a comparatively thin shelf succession with economic coals at Wankie, but in Northern Rhodesia the succession is much thicker and contains only seams of poor quality.

2. Petroleum

It is unlikely that any oil occurs in the sedimentary rocks of the area mapped but its structure and stratigraphy have some bearing on the oil possibilities of the Coast Province and should be mentioned here.

It has been considered by Busk and de Verteuil (1938, p. 16) that the Duruma Sandstones represent an exclusively continental deposit of sandstones laid down in a desert or semi-arid region. They recorded the succession as containing only a few relatively thin shale bands and, therefore, unsuitable for the formation of petroleum. This was a reasonable conclusion on the evidence available at the time, since the section was based mainly on outcrops of the Duruma Sandstones, which are generally restricted to massive arkoses and grits. The constituent series in fact contain considerable thicknesses of shale, as is evident from the log of the Maji ya Chumvi bore-hole (Miller, 1952, p. 29), and dark carbonaceous shales of one or two hundred feet in thickness are visible in some parts of the Galana section. Furthermore, the lower and middle Duruma Sandstones of the Mid-Galana area are composed of clastic sediments which were nearly always waterlaid and are in part interbedded with limestones, some of which are oolitic. It is apparent that they were deposited at the continental fringe of a wide unstable shelf and that only sediments deposited in deltaic, lagoonal, and marginal neritic environments can be seen in the visible outcrop. With increasing distance from source, however, it is highly probable that the sedimentary series contains a greater relative proportion of marine shales and limestone, beneath the Jurassic rocks of the Kenya coast.

In Madagascar the Karroo beds and overlying Jurassic and Cretaceous series were deposited on a subsiding basement in the western part of the island. The Karroo sequence contains a few marine horizons and compares stratigraphically with the Duruma Sandstones. In Kenya the younger beds are in the east and in Madagascar they are in the west, which is to be expected if they were laid down upon the eastern and western flanks respectively of the same geosyncline. Bituminous sandstones occurring in the lower part of the Isalo Series have long been known from the Morafenobe region of Madagascar, and recently oil impregnations have been noted in the lower Sakamena during core-drilling near Leoposa (Hedberg, 1954, p. 1482). Although the mobilization of small quantities of hydrocarbons from coal-bearing beds by later basic intrusions could perhaps account for these impregnations it is more probable that oil has migrated from petroliferous source rocks of marine geosynclinal origin occurring in the foredeep to the Morandava basin. Similar source rocks may, therefore, also be located in the western flanks of the geosyncline bordering the Kenya and Tanganyika coasts. Porous reservoir rocks capable of holding migratory oils are not likely to be found in the lower part of the Duruma Sandstones where the arkose and grits are well cemented and intercalated shales and sandstones are thin, but in the middle part of the series some of the reef-limestone in the Maji ya Chumvi shales, might possess favourable reservoir properties.

Some approximate absolute porosity ranges determined by bulk density measurements (cf. Branner, 1937) on samples taken from the lower and middle Duruma sandstones are given in Table IV and illustrate the low porosities of rocks in this part of the succession. The lower limit of porosity in sandstones producing oil appears to be between 12 and 14 per cent (Melcher, 1924, p. 727) and ranges up to about 35 per cent.

TABLE IV—ABSOLUTE POROSITY RANGES IN THE LOWER AND MIDDLE DURUMA SANDSTONES

Formation	*Sample*	*Mean Bulk Density*	*Porosity Per cent*
Taru Grits	Grey arkose	2.64	Nil
	Pink arkose	2.55	2–5
	Calcareous grit	2.67	Nil
	Felspathic grit	2.58	1–3
	Red grit	2.63	Nil
	Red sandstone	2.52	3–7
Maji ya Chumvi Beds	Yellow sandstone	2.53	3–7
Mariakani Sandstones	Mottled micaceous sandstone ..	2.55	2–5

No oil impregnations have been recorded in the coastal sediments, and it can be inferred that if oil has at some time accumulated in reservoir rocks it has either escaped or is held in stratigraphical or structural traps. A stratigraphical trap might occur under favourable conditions at the unconformity between the upper Duruma Sandstones and less porous Jurassic formations, but structural closure related to the deep pre-Jurassic faulting and folding of the coastal belt is more likely to have sealed-off suitable reservoirs.

To go beyond this general statement is outside the scope of the present report. Much detailed geophysical prospecting and trial drilling is necessary before the coastal oil prospects can be properly assessed. The Shell Overseas Exploration Company and the D'Arcy Exploration Company at present jointly hold an oil exploration licence* for an area extending to the eastern margin of the Mid-Galana area and including the Kenya coastal belt as far as the Equator.

3. Manganese

A pink or maroon-coloured manganese "bloom" is a common feature of many veins and fault-breccias in the Duruma Sandstones. On the western side of the Lali hills fault shatter-belts are well mineralized with manganese and iron in widely varying proportions. The breccias here consist of angular blocks and fragments of sandstones which are veined and covered with black ore containing pyrolusite (MnO_2), psilomelane ($((Ba,Mn)_2Mn_8O_{14}(OH)_4)$), and wad (an amorphous mixture of manganese oxides), the latter occurring in reniform or botryoidal aggregates in the shattered sandstone fragments. The sandstone breccias often show a zonal staining in pink and red near to the manganese ore. The associated iron-bearing minerals are specularite (Fe_2O_3), which forms foliaceous aggregates in the breccia cavities, reniform haematite (Fe_2O_3) and limonite ($2Fe_2O_3\ 3H_2O$).

The main localities at which manganese was noted are shown on the geological map.

An iron-manganese mineralized breccia in sandstones of the Lali hills gave the following analysis:—

	Per cent
SiO_2	24.40
Fe_2O_3	41.28
MnO_2	0.96
CoO	0.02

Analyst—Mrs. J. M. Stephens.

4. Lead and Zinc

Massive calcite veins follow N.-S. or N.W.-S.E.-trending faults which traverse the Duruma Sandstones in the north-west. The veins vary from thin stringers to comb-veins having widths of 6 in. or more. The largest recorded in the area outcrops on both banks of the Galana at approximate longitude 39° 6′ E. where a southward bend of the river carries it close to the Sala–Sobo track. Here a calcite vein 5 ft. in width is associated with narrower veins of the same trend in a reverse tear-fault striking 162° and dipping 50° west. Slickensiding in the fault-plane has a southerly component of 30° from the perpendicular. Drag effects in the sandstones are conspicuous, dips increasing to 50° near the fracture.

The veins, which have been noted in several scattered localities south of the Galana and west of Kulalu, usually have comb-structure and show no signs of lead or zinc sulphides in the body of the vein or in their walls, but chemical assay indicates the

* Assigned to the BP-Shell Petroleum Development Co. of Kenya Ltd. in January, 1959.

presence of small quantities of zinc and traces of lead. A typical calcite vein from Kuwetu gave the following analysis:—

	Per cent
Fe_2O_3	1.08
$CaO + MgO$	53.51
Pb	Trace
Zn	0.20
Ag	Nil

Analyst—Mrs. J. M. Stephens.

5. Graphite

Flakes of graphite measuring up to a centimetre across occur in the crystalline limestones of Kulalu. The flakes which often show a triangular etching on their faces, are evenly scattered between calcite rhombohedra or are sometimes concentrated in dark narrow bands a few inches in width, but the concentration seldom exceeds about 3 per cent.

6. Sillimanite

Sillimanite occurs in biotite schists and gneisses immediately west of the Lali hills and in the Galana at approximately 39° 17′ E. The alumino-silicate prisms are, however, small, intergrown with quartz and felspar, and seldom amount to more than 5 per cent of the rocks.

7. Mica

Small blocks of muscovite were found in the potash-rich granitoid gneiss of Sala and the western part of the Sala metamorphic block. They were also noted in pegmatite in the Galana at approximate longitude 39° 16′ E., but in both of these occurrences the mica is crossed by small fractures and hence is of no value.

8. Limestone

Large quantities of metamorphosed limestone are available in the Kulalu hills of the central part of the area, where individual limestone members reach a thickness of 800 ft. Analysis of a sample by W. P. Horne gave the low magnesia figure of 0.25 per cent. Some bands are very pure and may be expected to contain over 95 per cent of calcium carbonate. Localized impurities include calc-silicate minerals, olivine, and graphite, which are often concentrated in bands.

Unmetamorphosed limestones occur in some variety in the Duruma Sandstones. They are often thin and siliceous in the Taru Grits, but a pale grey reef limestone of the Maji ya Chumvi Beds outcropping at Kisusu hill is low in both magnesia and silica and would probably yield a fat lime on burning. About 500,000 tons of limestone are available for quarrying at Kisusu.

Two partial analyses of limestones from the Mid-Galana area are given below, together with analyses of the Jurassic Kambe limestone from the Mwachi gorge, near Mombasa for comparison.

	I	II	A	B
	Per cent	Per cent	Per cent	Per cent
SiO_2 (total)	2.12	12.29	18.86	9.26
MgO	0.38	0.76	1.14	0.17

I. Grey limestone. Kisusu hill (Maji ya Chumvi Beds). Analyst—Mrs. R. A. Inamdar.

II. Black limestone. Galana R. (Taru Grit). Analyst—Mrs. R. A. Inamdar.

A and B. Kambe limestone. Mwachi gorge (Wayland, 1927, p. 377). Analyst—Imperial Institute.

9. Road-metal

The few existing roads or tracks in the area mapped are generally passable at all seasons in the western part where the bed-rock is grit or sandstone, but in the east they cross a wide belt of poorly drained country underlain by shales of the Maji ya Chumvi Beds and are liable to remain waterlogged during the wet season. Any road development in this locality would hence involve the initial improvement of these sections.

In the north the most suitable source of road-stone for the Mambrui–Kitui road is the quartzite-flagstone of the Lali hills which could be quarried at mile 71 from Mambrui. Mariakani sandstone is also available between this road and the Galana river near mile 64 from Mambrui. In the south, hard white sandstones outcrop on the Garbete–Bamba road, and in the Mapotea escarpment. The tough and compact limestone of Kisusu hill situated close to the Garbete–Mapotea road would also be suitable as a source of road-stone for this section.

10. Water

Water-supply in the Mid-Galana area depends almost entirely on the Galana and Voi rivers. The former flows throughout the year, but the Voi is a seasonal stream which, with the construction of earth dams at Kandacha and Aruba in the Royal Tsavo National Park, has ceased to flow for any distance towards the coast. At the eastern margins of the area a sparse native population cultivates the margins of these watercourses, and their activity might be extended by the construction of irrigation dams on the Galana. Suitable sites are, however, few, and the soils at any distance from the river poor for cultivation.

The lower and middle parts of the Duruma Sandstones are not generally favourable as a source of bore-hole water. The yield from the Taru Grits of the coastal region is usually small, possibly because of the poorly sorted inequigranular nature of the grits and the filling of the intergranular spaces with secondary calcite. The overlying Maji ya Chumvi shales are of low permeability but interbedded sandstones make suitable aquifers. Unfortunately some of the middle Duruma Sandstones were deposited during periods of desiccation when mineral salts, mainly carbonates, chlorides, and sulphates were precipitated. The salts are disseminated throughout the succession with varying degrees of concentration, and being partly soluble, they are readily redissolved by ground-water, hence the water derived from these beds is often saline. For this reason, although the Kuwetu syncline is a favourable structure on which to site bore-holes and might be expected to give a higher than normal yield for the Nyika, its water is likely to have a high mineral content.

The only bore-hole recorded from the area was drilled by the Public Works Department at Jila in the south-east corner. The bore-hole, completed in 1949, is 328 ft. in depth and yielded 13,046 gallons of saline water per day. The chloride content is over 3,000 parts per million, rendering it unfit for domestic purposes but suitable for grazing cattle and goats.

VIII—RECOMMENDATIONS FOR FURTHER PROSPECTING

In view of the new evidence brought forward as a result of the mapping of the Mid-Galana area it is considered that hope of finding coal in the Karroo rocks of the coastal region should not be abandoned, and that more detailed exploration than has hitherto been carried out should be made. The search must be directed towards—

(*a*) defining the boundaries of the Karroo formations, including exploration for faulted inliers in the Basement System;

(*b*) defining the depth and configuration of the pre-Karroo floor by geophysical methods, and proving the probable concealment of the lower members of the Karroo succession;

(*c*) drilling the lower Karroo where minimum depths are indicated by (*a*) and (*b*) and in particular where topographical lows are discovered in the pre-Karroo floor.

The first of these requisites is being carried out by the Geological Survey in the course of its regional mapping.

The Galana plains and the Nyika are flat and have few outcrops, so that there is a limit to the geological information that can be obtained by surface survey, which must hence be supplemented by sub-surface data. For this reason it is important that the full results of all magnetic, gravity, or seismic surveys undertaken for whatever purpose, together with their geological interpretations, should be collated. Geophysical work directed towards the location of favourable oil structures is likely to be concentrated near to the coast and may, therefore, fail to provide sufficient information to enable an interpretation of the magnitude of the faults and the configuration of the pre-Karroo floor near to the western margins of the sedimentary outcrop, which is of importance in assessing the coal prospects.

Ground magnetometer surveys on the following traverse lines would produce useful information:—

(*a*) Galana river—Sobo rock (38° 45′ E.) to Divagu (39° 25′ E.).

(*b*) Voi–Sala road at 39° 00′ E., due E. to 39° 20′ E.

(*c*) Voi river. 39° 3′E. to 39° 25′ E.

(*d*) Mackinnon Road to Maji ya Chumvi.

(*e*) Kilibasi (38° 57′ E., 3° 57′ S.) to Kinango (39° 20′ E., 4° 10′ S.).

If gravimeter surveys were to be carried out accurate height control could only be obtained on traverse (d) and the eastern half of (*a*), where there are bench marks at 1-mile intervals. Under favourable circumstances such surveys might be expected to predict the depth to the Basement System surface with a probable error of 15 per cent. Where the predicted depth proves to be less than 500 ft., resistivity probes could be used to give confirmation.

Over the Nyika it is difficult to define the surface contact between Karroo rocks and the Basement System gneisses with any accuracy and it is possible that small inliers of sediments occur in the metamorphic rocks and remain undetected because of lack of outcrop. In these circumstances trenching can be used to prove the bedrock, but in view of the presence of superficial deposits which often include heavy kunkar encrustations, this method is uneconomical and the employment of a light drilling rig is to be preferred for shallow exploration west of the present known margins of the Karroo beds. A cable-tool of the type at present used for water-boring in the Colony would be suitable for this purpose. The sampling of material removed from the holes should be supervised by a geologist.

Final drilling at sites indicated as favourable by preliminary ground-survey and geophysical work, should not be undertaken without the intention, or the equipment necessary, to reach the base of the Karroo beds.

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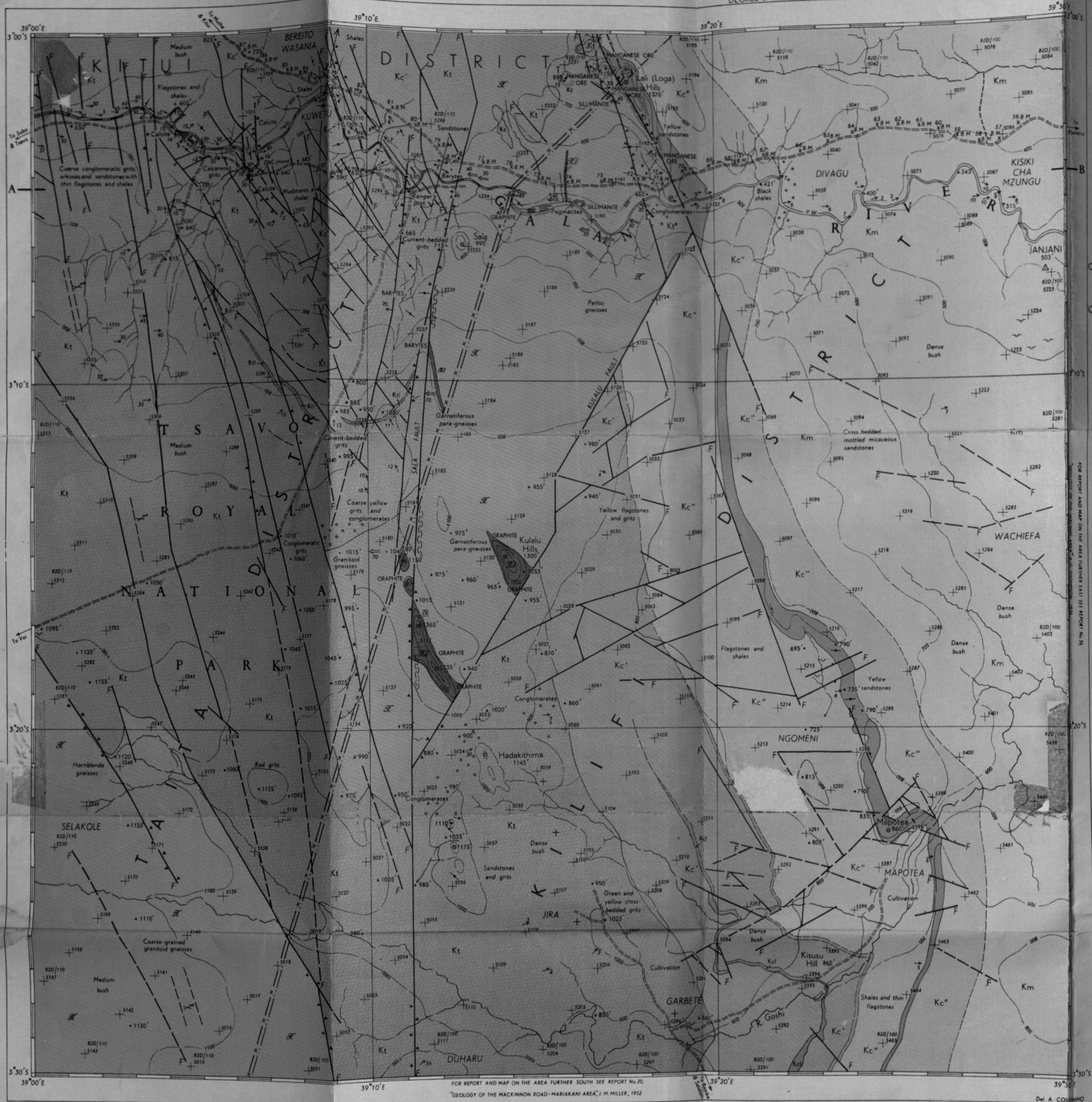
G.P.K. 1934—850—8/57

GEOLOGICAL MAP OF THE MID-GALANA AREA

DEGREE SHEET No.66. NORTH-WEST QUARTER (Directorate of Colonial Surveys Sheet No.191)



MINISTRY OF COMMERCE & INDUSTRY
MINES & GEOLOGICAL DEPARTMENT

Scale 1:125,000

1 inch=1·972 miles or 1·014 inches=2 miles

GEOLOGICALLY SURVEYED BY L.D. SANDERS, GEOLOGIST
Between October 1952 and April 1953
Photo-Litho, Government Printer, Nairobi

SECTION FROM A to B

Scale equal to that of map
Vertical scale = Horizontal scale