198
DOMESTIC

EAST AFR. PROT.

No. 44475

44495
Reg
Reg

Name or Individual.
...of W.B.

1907

Last previous Paper.
34235

(Subject.)

Report on Geology of Protectorate

Transmits

PRINTED FOR PARLIAMENT

(Minutes.)

Ack: & thank & then return papers to me.

at once.
H. J. R.
21/XII

Mr Antrobus agrees that the Report shd be printed for the Parly & [illegible]
(See [illegible] agree
H. J. R.
23/XII

Subsequent Paper.

199

Jan 17th 1908

Sir,

Herewith I return a corrected proof of "Report on Geology of E.A. Protectorate" together with the original. The map to illustrate this report was sent to the Colonial Office two days ago.

I am

Yours truly

H. Brantwood Muff

Supt of Printing
Colonial Office

Report relating to the Geology of the East Africa Protectorate.

This Report is reconstructed, and enlarged by the inclusion of additional observations from reports made to H.M. Commissioner in East Africa, and to the Manager of the Uganda Railway.

The field work was carried out in the period between December 1905 and September 1906. The geology of the country along the Uganda Railway from Mombasa to Port Florence was investigated, and several traverses were made from the Railway route. The chief of these were (1) from Gilgil along the eastern flank of the Rift Valley to Magatan, and thence to Rumuruti on the Laikipia Plateau. From Rumuruti a course to the south was taken through Nyeri, Fort Hall, and Kiambu to Nairobi; (2) from Naivasha to the Aberdare Mountains; (3) from Naivasha to the country east of Longonot volcano; (4) from Londiani to Eldoma Ravine and the Ndo Valley; and (5) from Port Florence to Rusinga Island.

Among previous accounts of the geology of the East Africa Protectorate reference may be made to Walcot Gibson, who gives a summary of the geology in East Africa in the 'Geological Magazine for 1893. J. W. Gregory has described the physical geography and geology of the country as far west as the Rift Valley in contributions to the 'Geographical Journal' for 1894, and to the 'Quarterly Journal of the Geological Society' for 1894 and 1900. A paper by Scott-Elliot and Gregory in the 1895 volume of the latter Journal refers to the geology of Nandi and Kavirondo. In his work entitled 'The Great Rift Valley' (London 1896) Gregory has summed up our knowledge of the geology of East Africa to that date. Since that time G.T. Prior has given an account of the microscopic petrography of

East African rocks in the 'Mineralogical Magazine' for 1903, and the late E.E. Walker's Reports on the geology of the East Africa Protectorate have been published (Cd. 1749, 1903).

A bibliography of works relating to East African geology and containing abstracts from those mentioned above, is published in "Notes on the Geology of the Continent of Africa" compiled by Alexander Knox (War Office Publication, 1905).

For geological consideration the better known parts of East Africa Protectorate may be divided into three broad regions, each of which is occupied by a distinct group of rocks.

(I) the Coastal Belt, formed of sedimentary rocks, which dip at gentle angles towards the coast,

(II) a broad region of gneiss stretching from the inner margin of the Coastal Belt inland to the edge of the Kapiti and Athi Plains,

(III) a vast region covered by volcanic rocks and extending from the Kapiti and Athi Plains westwards across the Rift Valley to the shores of the Victoria Nyanza.

In the country west of the Rift Valley, however, other rocks which include the gneiss of the region mentioned second above appear at the surface from beneath the volcanic rocks.

I The Coastal Belt.

(1) General description of Coastal Belt and Table of Strata.
(2) Raised Coral Reef and Kilindini Sands.
(3) Changamwe Shales.
(4) Duruma Sandstones.
(5) Superficial Deposits on the Duruma Sandstones.
(6) Water Resources on the Nyika.
(7) Water Resources on Mombasa Island.

(1) General Description of the Coastal Belt

~~(a) The Coastal Belt.~~

The Coastal Belt, which reaches from the coast to mile 87 along the line of the Uganda Railway, is again divisible into three zones running nearly parallel with the coast-line. These zones are plains, slightly dissected by denudation, which rise in steps one above the other towards the interior. Prof. Gregory speaks of these zones as (a) the Coast Plain or Tamberari; (b) the Foot Plateau, and (c) the Nyika. They are closely related to the three chief groups of sedimentary rocks which comprise the Coastal Belt. The Coastal Plain corresponds to the raised coral-reef formation; the Foot Plateau coincides very nearly with the shales of Upper Jurassic age, whilst the Nyika is composed of a thick series of grits and sandstones with subordinate shales, called the Duruma Sandstones. The beds are dipping gently towards the coast, so that as we proceed inland older and older beds are encountered in spite of the fact we are rising steadily to over 1,000 feet above sea-level. The openings and cuttings made for the construction of the Uganda Railway have provided a number of sections, which permit of a more complete examination of these beds than was possible formerly.

The simple structure previously recognised as due to a succession of beds dipping at an average angle of about 15° towards the east-south-east has been confirmed. The Duruma Sandstones have been found capable of subdivision into four well marked lithological groups. Beyond Ammon-ites and Belemnites of Upper Jurassic age already known from the shales of the Foot Plateau, few fossils have been obtained. These are chiefly fragmentary plant remains, poorly preserved, and only partly determinable. They tend to show, though they do not prove conclusively, that the sedimentary beds of the Coastal Belt are of Trias- Triassic and Jurassic age. Shales containing fossils of Permo-Carboniferous age are recorded by Prof. Gregory as occurring on the Sabaki River, by the 'Second Stockade' (lat. 3°3'S, and long. 39°5'E), but it is doubtful whether any strata of this age occur in the Coastal Belt where it is traversed by the Uganda Railway.

The following table gives the succession of beds in the Coastal Belt:-

	Raised coral-reef and Kilindini Sands (Unconformity).	Pleistocene
	Changamwe Shales with limestone near base.	Jurassic
Duruma Sandstones	Mazeras Sandstone, with pisolitic limestone near top.	
	Mariakani Sandstone	
	Maji-ya-Chumvi Beds	? Triassic
	Taru Grits.	
	(Unconformity).	
	Gneiss.	Archaean.

2. Raised Coralline Reef and Kilindini Sands.

These beds form the coastal plain, which is about two miles wide at Mombasa and rises to an average level of 70 feet above low water-mark. The limestone is a porous rock, very often a breccia consisting of fragments of corals, molluscs and other marine organisms. The limestone composes the southern or seaward portion of the Island and extends in two short arms along the shores of the estuaries. On the eastern side it extends some distance north of Mombasa. On the western side in the new railway cuttings between the Mombasa line and Kilindini pier, its top dips down to the north and is covered by a sandy limestone, which gradually gives place to sands. The limestone is not seen again in the cliffs to the northward, but it appears in the railway cuttings between Kilindini and the Makupa Bridge between mile 1/5 and 1/10*

The rest of the island is formed of fairly coarse clean sand, which is often cemented by calcite into a sandstone. The sand grains are chiefly of quartz with the angles and edges rounded off. Sikeoni mentions the occurrence of grains of orthoclase, garnets and syenite, whilst Gregory[2] notes in limestone at Kilindini grains of garnet, orthoclase, microcline, plagioclase, tourmaline, &c. - minerals which all occur in the sandstones or gneisses inland.

* The mileage is that given on the telegraph poles beside the railway and is reckoned from Kilindini. The numerator of the fraction gives the miles, the denominator the number of the telegraph pole from the preceding milepost. The telegraph poles are placed at intervals of 100 yds.

1. Geol. Mag. (1893), p. 561.
2. Quart. Journal, Geol. Soc. vol. 56, p. 227 (1900).

The rocks of the coast plain are doubtless a fringing reef formed when the sea level stood some 70 feet higher relatively to the land. The present harbours on each side of Mombasa Island mark the gaps in the reef opposite the mouths of the Mwachi and Mwandoni Rivers and the Kilindini sands were accumulated in the lagoons behind the reef.

On crossing to the mainland we find at the railway bridge abutment a small mass of Kilindini sands banked against the Jurassic shales of Changamwe, whilst a small island to the north of the bridge consists of the cemented sands resting unconformably on the shales. The coastal plain, however, is continued inland for some distance across the edges of the Jurassic Shales, which just before reaching Changamwe Station rise up to form the Foot Plateau. The steep slope formed by the shales at the edge of the Foot Plateau is doubtless the degraded sea-cliff of the raised reef period, whilst the breadth of the plain cut across the Jurassic shales is some measure of the marine erosion during the period of formation of the coral reef.

The limestone in the southern part of the island is commonly close to the surface, or covered by limestone rubble and a few feet of ochreous reddish brown clay loam. The outcrop in the railway cuttings beyond Kilindini is overlain by a dark red clay, which is probably a true terra rossa. The soil overlying the Kilindini sands is a light sandy brown loam often several feet thick.

3) The Changamure Shales.

Behind the Coastal Plain, the Foot Plateau forms a belt of land about 6 miles wide, which attains an average height of 200 feet above sea-level. The Uganda Railway crosses it on the peninsula lying between Port Tudor and Port Reitz, the landward continuations of Mombasa and Kilindini Harbours respectively. The whole peninsula is formed of the Changamure Shales, a thick and uniform series of dull, olive-green, friable shales. They are slightly sandy and micaceous and contain nodules of clay-ironstone and argillaceous limestone on some horizons. The limestone nodules would yield a hydraulic lime, but they were nowhere found in sufficient quantity to be worth collecting for calcination. The shales, which have an outcrop nearly seven miles broad, overlie apparently quite conformably the Mazeras sandstones, the highest member of the Duruma Sandstone Series, which rises from beneath the Shales to form the line of hills on the inner margin of the Foot Plateau. The outcrop of the shales runs parallel with coast, but is reported to disappear before reaching Takaungu to the north-east and Tiwa to the South-west. ~~To the north north east, it probably narrows quickly but to the south south west it extends into German East Africa.~~ The shales are first met with in the railway cuttings between the Makupa Bridge and Changhamure. They are, however, here more disturbed than usual and thrown by faults (mile 2/2). It is from this locality, from the hills on the north shore of Port Tudor, that the fossils, ~~were obtained~~ which proved the Upper Jurassic age of the Shales, ~~The presence of Aspidoceras acanthicum indicates the horizon to be Kimmeridgian.~~ were obtained by Hildebrandt in 1876. Some fossils obtained from the topmost beds of the Shales on the track between Rusaoni (Freretown) & Takaungu indicate that the youngest part of the strata are probably of Lower Cretaceous age.

The Changamwe Shales are exposed in numerous cuttings from mile 9 to mile 11/6 where they give place on the flanks of the scarp between the Foot Plateau and the Nyika to the Duruma Sandstones.

In the deep cutting at mile 10/5-7 there is a remarkable line of coarse grit boulders embedded in the shales. One ~~mass~~ very much larger than the others measures 24 feet in length and about 15 feet in height. Lithologically the boulders are similar to parts of the Mazeras Sandstones or the Taru Grits, but it is not easy to explain ~~thatxps~~ their presence in the Shales. The dip of the Shales which hitherto has been 10° to S.E. is here increased to 25° and it maintains a higher angle (14° to 25°) to the base of the Shales.

In the cutting at mile 10/14 a change of lithological character sets in, which marks the passage from the Duruma Sandstones of terrestrial origin to the marine Changamwe Shales. The Shales become brown or purple and are interbedded with lenticular bands of micaceous sandstone, which bear fossil sun cracks and rain prints on their surfaces. These beds are traceable to mile 11/6, where they are underlain by the upper beds of the Mazeras Sandstones on the hill ~~slope~~ above the track.

In the deep cutting close to Changamwe Station, the Shales, which contain ~~septaria~~ clay ironstone nodules and thin bands of calcareous and ferruginous sandstone, are overlain by 6 or 8 feet of deep orange-coloured loam. The junction is uneven, though very sharp and no weathered remains from the Shales are to be seen in the loam. From Changamwe Station (mile 4) to mile 9, the railway passes through cocoa-nut plantations situated on a gently rising plateau covered by the loam. The shales are nowhere seen at the surface, but the bluffs along Port Tudor and Port Reitz, although greatly obscured by vegetation are sufficient to prove the continuity of the Shales beneath the loam.

Just before reaching mile 9 the loam ceases abruptly and the Changamwe Shales again appear at the surface. Although we are still traversing the Foot Plateau at an altitude of about 200 feet above the sea, the aspect of the country is very different from that of the rich plantations just left behind. Here is practically no soil; the grass is coarse and scanty, the trees small, sparse and thorny. It is evident that the plantations around Changamwe owe their fertility to the covering of loam, which absorbs much of the rain falling on it, and that the area as of possible cultivation in the Foot Plateau is limited to the districts covered by the loam. Beyond its limits the land is cut up by numerous deep and steep-sided ravines which carry off all the rain directly into Port Tudor and Port Reitz. By this powerful surface run-off all the fine surface debris, which is derived from the decomposition of the rocks at the surface, and might accumulate under more favourable conditions to form a soil, is borne off into the sea.

The ravines are streamless except during and immed-
-iately after rain. Their rock-floors in many cases pass beneath low water mark and the lower reaches are sometimes occupied by arms of the sea, sometimes filled up with alluvium, which is fertile and often cultivated. It is ob-
-vious that the valleys were eroded at a time when the land stood higher relatively to the sea than it does at present. In view of the fact that the raised coral-reef has always been assigned to a very late geological date, it is somewhat surprising to find that this period of up-
-lift and denudation is really later than the formation of the reef. It is important to note that there is no trace of the coral-reef formation in the estuaries which are eroded in the Changamure Shales and Mazeras Sandstone. On the other hand the coral-reef formation it-
-self, including the Kilindini Sands, is eroded into valleys which pass beneath low water mark. Good instances of these are seen in Mwema Creek, opposite Telegraph Point at Kilindini and in the broad nameless valley, which enters Port Tudor opposite the north-east corner of Mombasa Island.

It is evident therefore that after the formation of the coral-reef, the land was elevated relatively to the present sea-level. It is difficult to estimate the magnitude of this movement, but some indication may perhaps be obtained from the soundings recorded on the Admiralty Chart (No. 666). It is fairly clear that the partially submerged valleys notch the 10 fathom submarine contour. Depths of over 20 fathoms are very common in Kilindini and Mombasa Harbours, whilst a few soundings of more than 30 fathoms are recorded. The detritus brought down by the streams at the present time is deposited on the mudbanks in the upper reaches of Ports Tudor and Reitz, and the tidal scour is probably sufficient to prevent its accumulation in the harbours. On the other hand it is impossible to say whether the tidal scour has effected any submarine erosion, or whether solution of the limestone is respons-ible for any considerable deepening of the harbours. It is, however, practically certain that the elevation must have amounted to at least 60 feet and it may have doubled that amount.

During this emergence of the land considerable denu-dation took place, pre-existing valleys were deeply cut down, new valleys were eroded in the raised reef & Kilindini Sands, and considerable areas of the reddish loam of the Foot Plateau were removed. This denudation was brought to an end by a return of the sea to its present position some seventy feet lower than its level at the time the raised reef was formed. Thus, the conclusion arrived at is that the last movement on the coast has been a subsidence of the land and not an elevation, as might appear to be the case on a first inspection.

At the return of the sea to its present level Mombasa Island became separated from the ~~continent~~ mainland. The sea then invaded the valleys of two tributary streams which had cut back their valleys during the previous period of uplift to a low col ~~which is at the present day the shallow ford at Makupa~~ on the site of the Makupa causeway.

(4) The Duruma Sandstones.

The Duruma Sandstones occupy a poorly watered upland belt of country known as the Nyika, which rises behind the Foot Plateau to heights of 500 to 1,600 feet. The belt runs roughly parallel with the coast and where crossed by the Uganda Railway is some 45 miles broad. Northwards near Takaungu the Duruma Sandstones appear to reach the coast. Southwards they form the Shimba Hills and are doubtless tobe correlated with the sandstones, grits and shales mapped by Bornhardt in the Amboni Hills behind Tanga, German East Africa. Bornhardt points out that the latter are litho-logically identical with a series of sandstones, which form a nearly continuous border on the eastern edge of the gneissic region of German East Africa and with the coal-bearing beds of the Nyasa region. In the beds of the two latter districts the plant-remains include Glossopteris or Vertebraria which prove the Permo Carboniferous age of the beds, but in the rocks of the Amboni Hills there have been found only coniferous remains referred by Potonie to Voltziopsis and believed by him to indicate a horizon between Keuper and Middle Jurassic (Bornhardt, Zur Ober-flachengestaltung und Geologie Deutsch-Ostafrikas, p. 505).

The fossil plants found at mile 38/11 in the second lowest sub-division of the Duruma Sandstones (the Maji-ya-Chumvi beds) have been identified by Mr E.A.Newell Arber, M.A., F.G.S., as Thuyites and Carpolites. The small crustacean Estheria is also found in the same series of beds. As Thuyites is not known to be older than the Meso-zoic era, its occurrence with Estheria in the same thousands of feet below the Upper Jurassic is strongly suggestive of a Triassic age. But if this be granted, it still remains uncertain whether the Taru Grits which lie beneath the Mayi-ya-Ghumvi beds, may not be of Permo-Carboniferous age.

(a) The Mazeras Sandstones. The topmost beds of the Duruma Sandstones, which pass beneath the Changamwe Shales are exposed in the cutting at mile 11/10 on the Railway. They consist of coarse grained massive reddish sandstones and contain prostrate silicified tree-trunks lying in a N. and S. direction. One of these measuring 1 foot 4 inches by 9 inches in cross-section was excavated for a length of four feet and taken down to Mombasa. Mr Newell Arber refers this wood to the genus Cedroxylon.

The underlying beds are well exposed in a series of deep cuttings between miles 11/13 and 12/13. They consist of medium grained white sandstones in beds from 12 feet to over 45 feet thick, separated by bright green marls with occasional purple bands. The marl bands are from 3 to 25 feet thick and are but poorly laminated. The sand-stones are very white and consist of grains of quartz, felspar and quartzite, set in an opaque white cement which consists of minute scales of white mica. The latter mineral forms but a poor cement, which allows the grains to loosen and fall away. The edges of the beds, which have been exposed for only a few years in the cuttings, are distinctly rounded. Hence these sandstones would make but a poor building-stone. The beds dip at angles varying from 8° to 11° towards some point between N. and W. i.e., towards the interior. They are affected, however, by several faults trending on an average N.60°E and throwing down to the south-east, so that the effect of the local inward dip is largely counteracted. Two of these faults are seen at mile 11/15 and a third passes the end of the cutting at mile 11/17. The latter fault splits into two, one branch of which crosses the line at mile 12/3, whilst the other branch is well seen in the cutting a little beyond. The succeeding exposures at mile 13 show a coarse grained sand-stone with banded bluish-grey and white shales, followed by exposures of white sandstones with green marls similar to those already described. The next outcrops at Mazeras Station are sandstones of a different type and are grouped as the Mariakani Sandstones.

On the south side of the railway between mile 11 and 12 the Mwachi River runs in a horse-shoe shaped ravine 300 to 400 feet deep. On the flanks of the ravine and in the bed of the river, the Mazeras Sandstones are frequently seen at the surface, but the interbedded shales are nowhere exposed. From the lower limb of the horse-shoe bend the river turns at a right angle to the south-east and passes through a short gorge, which opens out into the upper waters of Port Reitz. This gorge, together with the lower portion of the horse-shoe bend is tidal, but there is no evidence of the sea having ever penetrated further up than it does at present, as must have happened if the gorge had been eroded to its present depth before the raised coral-reef of the coast was being formed. It is, indeed evident that the horse-shoe bend is an 'incised meander' and that it was deepened during the period of uplift, which has been already shown to have followed the formation of the raised coral-reef.

On the flanks of the Mwachi gorge the coarse grained sand-stones are dipping regularly at about 15° to 30°S.E. Here they include a bed of greyish limestone about 30 feet thick, which contains pisolitic and oolitic bands, & sometimes pebbles of limestone and sandstone. Quartz grains increase in number towards the top of the limestone, which passes gradually into a coarse grained sandstone.

The pisolitic limestone may also be traced north-eastwards towards the railway. It was found to occupy the forest-covered summit of the hill S.W. of mile 11/13. It is probable that a fault crossing the line near mile 11/6 throws down the beds to the north so that the limestone outcrop is transferred to the north side of the line. It is not exposed here, but blocks of limestone were found in the nullah about 100 yards above mile 11. Outcrops of limestone were also observed on the native track, which runs in a north-westerly direction in the angle between the railway and the old Mazeras train-line at mile 10/14.

Returning to the section in the estuary of the Mwachi the sandstone lying above the limestone is in turn succeeded by the Changamwe Shales, which form very much lower bluffs and at the same time the estuary widens out.

Some little distance from the base of the Shales, a bed of hard grey compact limestone, perhaps 8 or 10 feet thick is interstratified with the Shales. It contains small subangular grains of quartz with a few of felspar in a matrix of finely granular calcite. Foraminifera and fragmentary remains of lamellibranchs, echinoderms, and probably of brachiopods are preserved in clear calcite. The only complete fossils observed were <u>Ostraea</u>. The limestone on calcination produced a very fat lime. The outcrop of the limestone was traced in a north-easterly direction towards the railway. It is shifted by several faults, which run in the direction of the dip of the beds. The best exposure near the line is on the north-ern flank of the [illegible]

A search around the head of Port Tudor would doubtless reveal these beds of limestone to the north-east, and the extension to the south-west of at least the upper bed seems proved by a specimen brought back from the Shimba Hills by the Director of Public Works.

(b) The Mariakani Sandstones. Returning to the section along the railway, the Mariakani Sandstones, which underlie the Mazeras Sandstones, are found to extend from Mazeras Station to mile 31/0, a distance of about 13 miles. They consist of fine-grained yellow sandstones often false-bedded and interstratified with sandy micaceous shales. The grains are chiefly of quartz, but grains of alkali-felspar slightly decomposed are abundant. Black and white mica occur in long wavy scales between the quartz and felspar grains. There are present also, grains of apatite, zircon, and tourmaline. In many beds the interstices between the grains are filled with finely divided mica, a poor cement, which allows the rock to crumble away grain by grain. The abundance of the mica flakes in many beds causes the rock to split too readily along the bedding planes to make a good freestone. Between mile 17 and Mazeras the sandstones are generally harder and less fissile than those further up the line.

Between Mazeras and the old station at Mariakani (mile 24) the beds are rolling gently at low angles, whilst beyond mile 24 the dip is fairly constant at about 4° to S.E. These sandstones are exposed in the bed of the Mwachi River at the Mazeras pumping station, and at intervals along the pipe-line.

(c) The Maji-ya-Chumvi Beds. Immediately after passing off the Mariakani Sandstones the Maji-ya-Chumvi Beds appear at the surface. They consist of repeated alternations of dull greenish mudstones with very hard sandstones, the former predominating. There are numerous exposures of these beds between mile 31/9 and Maji-ya-Chumvi Station (mile 32), but their outcrop is not finally passed until mile 41 is reached, close to Samburu Station.

The sandstones are very compact and hard, generally greenish in colour but stained reddish-brown on the outside. They often run in ribs less than a foot thick, but there are also many posts 5 feet or more in depth. Joints are well developed, and are commonly from two to four feet apart, in the thicker beds. The mudstones are of a dull greenish-grey colour and break up with the usual irregular fracture. On the north side of the railway at mile 31/10, and also beside the path to the pumping station 8 minutes north of Mayi-ya-Chumvi station, the mudstones contain carbonaceous specks evidently plant remains, but unfortunately all too fragmentary for determination. At the latter locality one of the shale bands contains numerous Estherias. remains of Estheria

Beyond the pumping station and up to the head of the Mayi-ya-Chumbi River sandstones are frequently exposed in the bed of the stream dipping at 3° to 15° to points varying from N.56°E to E.20°S.

On the railway beyond Maji-ya-Chumvi Station similar beds are seen in the cuttings. A thick sandstone forms a prominent escarpment, which trends N.N.E.-S.S.W. and is crossed by the railway at mile 36. Its southward prolongation is named the Ndungumi Hills on the War Office map (I.D.W.O. Sheet 94, Q.) and is well seen from the railway about mile 37.

The scenic features in the district occupied by the Maji-ya-Chumvi Beds are more varied than those of the Mariakani Sandstones or Taru Grits. This is due to the greater differences of hardness in the strata composing the Maji-ya-Chumvi Beds. A belt of shales and mudstones is marked by a broad nearly flat floored hollow, whilst the thicker bands of sandstone, like that noted above, form ridges having a short and relatively steep escarpment facing the west and a long gentler dip-slope on the east. These ridges are broken through by the valleys of the main rivers, though there are very few permanent streams in the district. The whole of the surface features indeed, are explicable as the result of the establishment of a river-system on a gently inclined group of rocks, of varying hardness. That the system is in an early stage of development is shown by the small importance of strike valleys as main valleys. The chief work of the streams, which are operative at intervals only, is to carry off the fine particles formed throughout the year by the disintegration of the rocks and washed down by the heavy surface run-off during the torrential rains.

Shallow cuttings between miles 38/6 and 38/14 expose sandstones minutely laminated by extremely thin layers of shaley material and splitting into small 'stone-slates' usually ¼ to ½ inch thick. The beds are dipping at 9° to E.25°S. and close to the surface are often greatly dis--turbed. It is noteworthy that a surface-slope of only 2° is sufficient to admit of soil-cap movements, which turn up the ends of the beds and cause an erroneous conception of the dip to be obtained from a mere surface exposure.

At mile 38/10-11 plant remains preserved in the dark partings of these fissile sandstones have been identified by Mr E. A. Newell Arber as belonging to Thuyites and Carpolites, as already noted.

Fissile and sometimes ripple-marked impure sandstones are exposed at intervals as far as mile 41, close to Samburu Station. Here the Taru Grits, which underlie the Majimwa-Chamvi beds first appear at the surface.

(e) The Taru Grits. These grits have frequently been referred to by travellers, whose attention was no doubt arrested by the extensive bare pavements and occasional hummocks of rock, whilst the hollows weathered out in them contained the last water the travellers of pre-railway days might expect to meet before gaining the far side of the Taru Plain, some 47 miles away.

There are frequent exposures of grit along the rail--way and in the scrub on both sides of it nearly as far as mile 57. Beyond this point the Archaean gneiss crops up, but the basement beds of the grit and their junction with the gneiss are not exposed.

The grit, across its whole outcrop, which is about 12 miles broad, varies very little. It is a massive, current

-bedded, felspathic grit composed of grains of very un-
-equal size. Only a proportion of the larger fragments are rounded, whilst the smaller grains are usually quite angular. Felspar, chiefly microcline and albite, is abund-
-ant and nearly always in a fresh condition. There also occur grains of garnet, graphite, white and black mica, hornblende and zircon. All these minerals occur in the gneiss by the denudation of which the grits have been directly formed. The grains in the grit are closely packed together, and an apparent interlocking of the grains is due to a secondary deposition of quartz. This cementation has proceeded to a depth of over 450 feet from the surface as proven by specimens from the Samburu bore. It must diminish appreciably the porosity of the rock and its capacity to transmit water. The grits further contain pebbles of pegmatite, which are common as veins in the gneiss. A coarse conglomerate exposed in the nullah about half a mile south of Samburu Station contains many pebbles of gneiss over an inch long. Finer beds of grit showing suncracks and worm-tracks on their surfaces are seen west of the Station buildings at Samburu and also at mile 56/12.

The grits are traversed by two sets of widely spaced joints, too widely spaced indeed for convenience in quarry-ing even for heavy masonry. Ngarunga, as the local water-
-holes are called, are very often widened joints. The standing water attacks the alkali silicates in the felspar and brings about its decay, whereby the grit very slowly crumbles down to a quartz sand.

Yellowish rather sandy and slight micaceous shales with thin grey marly partings were exposed in a cutting on the diversion just beyond mile 53/13. Obscure plant-

Dark shale	1	2	279	4
Sandstone with coaly specks	1	5	280	9
Black and sandy shales	3	6	284	3
Grit	4	8	288	11
Black shale	2	-	290	11
Coarse and fine sandstone	7	10	298	9
Black and sandy shales	7	10	306	7
Grit	1	-	307	7
Black shales with sandy bands	3	5	311	-
Sandstone with grit and shale bands	13	10	324	10
Banded shales	1	5	326	3
Grit with some sandstone	130	2	456	5
Black shales with worm tracks	6	10	463	3
Grey sandstone	1	6½	464	9½
Black shales	62	3	527	-½

The shales passed through in this bore are black and micaceous and contain obscure traces of plant remains. Several of the sandstones, also contain numerous black carbonaceous specks. Though the age of these beds is not settled, it has been pointed out that they are probably either Permo-Carboniferous or Triassic. Workable coal seams are found in beds of th[illegible] above age both in India and South Africa. The possibility of coal being found on horizons from the Taru grits upwards to the Mazeras Sandstones should not be overlooked. The borer at Samburu, to judge from his reports which I have seen, was aware of this and is, therefore, not likely to have passed through a coal seam unknowingly.

(4) Superficial Deposits on the Duruma Sandstones.
In the neighbourhood of Mazeras the sub-soil is a yellow-ish-red sandy loam, which covering the gentler slopes, whether they be the tops of hills or the floors of valleys, to a depth of two to six feet. On the steeper hill slopes it is usually very thin or absent. It is not unlike the loam of Changamwe, but contains more sand. On the Mariakani sandstones, the soil is of course eminently sandy. It is yellow, brown or greyish rather than red and though thin is fairly uniformly distributed. On the Maji-ya-Chumvi beds the soil is generally very thin and, except in the valleys, is usually only a thin layer of rubble. A black clay, similar to the black cotton soil, sometimes forms terraces along the banks of the more permanent rivers. These terraces are a common situation for the natives' plantations. A deposit of white rubbly limestone (kunkar) is frequently found at the base of the black soil. It may be several feet thick, and is mixed more more or less with clay. Apart from its association with the black cotton soil, 'kunkar' occurs only in small isolated nodules in the superficial deposits of this part of the country.

The Taru Grits disintegrate into a course sandy soil of a brown or grey colour. A few miles beyond Samburu, however, the colour changes to bright red first of all on the ridges, where the soil is drier. On the slopes and in the hollows the soil remains a dark-brown sand, but it is occasionally replaced by black clay soil in some of the valleys. Finally on approaching the edge of the Taru plain the soil takes on the uniform bright red tint, which characterises the gneissic region. The change of colour is due to the partial or complete dehydration of the iron-

-oxides apparently as a result of greater aridity of the climate.

(5) Water Resources on the Nyika.

(a) Small proportion of rainfall absorbed.

(b) The boring at Samburu.

(c) A boring west of Samburu.

(d) Storage Reservoirs.

(a) There are very few statistics for rainfall for the Nyika, but the annual amount seems to vary exceedingly as it does in other parts of East Africa. At Mackinnon Road Station, situated about 25 miles west of the outcrop of the Taru grits, the rainfall during 1904 and 1905 was 41·44 and 36·47 inches respectively, or rather more than three fourths of the amount recorded at Mombasa during the same period. At Mazeras on the eastern edge of the Nyika, the rainfall appears to be a few inches less than that of Mombasa.

The rain descends in short, violent showers. There is a large surface run-off, which fills the stream-courses with floods of short duration. The sandy soils absorb a part of the rainfall, but a large portion of this is evaporated or transpired by the vegetation. The amount of evaporation is unknown, but it would be greatly in excess of the rainfall, whilst the water taken up by the vegetation can be by no means negligible. In these circumstances only a very small percentage of the total rainfall can percolate into the rocks to join the underground water. Moreover the cementation of the grits, which has already been noted diminishes the permeability of the rocks. It is evident, that in spite of the amount of the rainfall, very little water percolates into the rocks to replenish an underground reservoir.

(b) A diamond-bore was put down at Samburu because water was required there for the Railway. It commences close to the top of the Taru Grits where they are overlain by the Maji-ya-Chumvi Beds, which are chiefly impervious shales. Since the outcrops of the Taru Grits is about 12 miles broad, and the dip not less than 5°, the thickness of the Grits is at least 4,000 feet. There is, therefore, no chance of the boring reaching the base of the Grits. Furthermore it is evident that the conformation of the ground, considered in relation to the geological structure cannot provide sufficient 'head' to cause a flowing well.

Samburu is 910 feet above sea-level, and the bore was carried to a depth of 527 feet. The continuation of the bore for another three hundred feet would test in a conclus-ive manner the presence of a reservoir of water at a low level; but, if the water were found, the cost of pumping, apart from interest on capital outlay in widening the bore and in machinery, would be greater than that of the present system of running water-tanks on the trains.

(c) A boring put down west of Samburu, which would reach the base of the grits at a moderate depth (say 200 feet) has nothing to recommend it. Whilst a basin-like hollow in the underlying floor of gneiss might hold water at a moderate depth, the prediction of the site of such a hollow is practically impossible; and, if struck by chance, the supply could not be relied on as permanent, on account of the small percolation from the surface.

(d) Apart from such considerations as the cost of the works and the large loss by evaporation, the country where water is required is not very suitable for the con-struction of storage reservoirs. A more suitable position would be in the relatively deep valleys south of Maji-ya-Chumvi or of mile 36. Here a site could be selected having an impervious floor of shales and a large catchment basin, whilst the dam would be relatively short. As, however, such a site would be below and east of that part of the railway where water is required, the subject need not be considered further.

(3) Water Resources on Mombasa Island.

(a) The present supply.

(b) The prospect of success of a deep bore.

(a) On Mombasa Island the supply of water is obtain-ed at present partly from stored rain-water and partly from shallow wells sunk in the coral-reef limestone or Kilindini sands. The wells are 65 to 70 feet deep, i.e., they are sunk to sea-level. The water is hard and slightly brackish, but the salinity is not due to the percolation of sea-water, as shown by the following analyses of water from Kilindini wells, by Messrs Stanger & Blount:-

	No. 1. Grains per gall.	No. 2. Grains per ga
Silica (SiO_2)	4·24	3·31
Alumina & Ferric oxide (Al_2O_3 - Fe_2O_3)	0·25	-
Lime (CaO)	13·06	10·29
Magnesia (MgO)	3·39	1·73
Soda (Na_2O)	6·42	5·27
Sulphuric anhydride (SO_3)	0·82	Nil
Carbonic anhydride (CO_2)	10·32	11·85
Chlorine	8·61	3·09
	46·21	36·07
Deduct oxygen equivalent to Cl.	1·94	0·70
	44·27	35·37
Combined water, organic matter and Loss.	7·67	4·53
Total Solids.	51·94	39·90

The chief salts probably present are therefore:-

Calcium carbonate	23·32	18·38
Magnesium carbonate	-	3·63
Magnesium sulphate	1·23	

Magnesium chloride	4·70	-
Sodium carbonate	-	4·41
Sodium chloride	8·40	5·96

The salts are present in proportions altogether different to the proportions found in sea-water, whilst the great excess of calcium carbonate is due to the per-colation of rain-water from the surface through the coral limestone and sands, in which there is abunant calcite.

The ground-water is replenished by percolating rain-water and is held up by the sea. Since the rocks are very porous, the water escapes out to sea by along the shores, particularly between tide-marks. Hence the water-table has a very gentle gradient and rises very little above high water-mark. A well sunk below high water mark at almost any spot on the island (even on the sea-shore) is practically certain to tap this supply of slightly saline water.

(4) In the likely event of a larger supply of water beig required at Mombasa, the possibility of a deep boring proving successful may be considered, though the informat-ion available is not as full as could be desired. A deep bore put down on Mombasa Island would, after piercing the coral limestone or Kilindini sands, pass through the impervious Changamwe Shales and finally enter the porous Mazeras Sandstones. The examination of the outcrop of the Mazeras Sandstones, described previously, showed that the water-table in them is at a low level. The sandstones have been cut down to sea-level in the estuary of the Mwachi River and here water escapes from them in small springs at and below the level of high tide-mark. Beneath Mombasa the water must be under considerable pressure and

ld rise in the bore-hole to within easy pumping distance of the surface, but the 'head' of water is insufficient to produce a flow at the surface.

The depth to which such a boring would have to be carried depends largely on the thickness of the Changamwe Shales. With the information at hand a reliable estimate of the total thickness cannot be made. Owing to the uni-formity of the beds it is impossible to make allowances for the folding and faulting between the Makupa Bridge and Changamwe. Again for 9 miles (Changamwe to mile 9) the shales are not exposed along the railway: and the bluffs of Port Tudor and Port Reitz, whilst sufficient to prove the continuity of the shales, are too overgrown to give precise information as to thickness of the beds. The careful collection and identification of fossils would probably show to what extent they are repeated at the sur-face. From mile 9 to the top of the Mazeras Sandstones the beds are not greatly disturbed, and a calculation from dips plotted on a large scale map gives 1,500 feet as the thickness of the shales between these points.

It appears that a boring on Mombasa Island might have to pierce a very great thickness of shales, but one put down near mile 9 may be expected to strike water at a depth of, roughly, 1,800 feet. A more convenient site might perhaps be selected on the shores of Port Tudor and Port Reitz. The ironstone-nodules, which occur on some horizons in the Changamwe Shales, might prove troublesome in sinking the bore, otherwise the strata are 'soft' with only a few hard beds.

The fact that the Mazeras Sandstones dip eastwards beneath the impervious Changamwe Shales is generally favourable to the success of artesian wells along the coast, where this structure obtains. Other places on the coast may be in a more favourable position than Mombasa for obtaining water in this manner, but an examination of the geological structure of the district is necessary.

favourable to the success of artesian wells along the coast, where this structure obtains. Other places on the coast may be in a more favourable position than Mombasa for obtaining water in this manner, but an examination of the geological structure of the district is necessary.

II. The Gneissic Region.

(a) Extent.
(b) Mineral composition of the gneiss.
(c) Gneiss in the country between Mumugu and Machakos Road.
(d) Gneiss at Fort Hall.
(e) Gneiss in Elgeyo.
(f) Gneiss around Muhoroni.

(a) The second region is that occupied by the Archaean Gneiss and stretches from the inner margin of the Coastal Belt (mile 57) inland to the edge of the Kapiti and Athi Plains (mile 283), thus including the greater part of the eastern half of the Protectorate. Within this region the gneiss - well called the foundation of the African continent - forms bold hill-ranges and isolated peaks. There are, however, several areas where it is covered by volcanic rocks of the same general age as those of the Rift Valley. These volcanic rocks occasionally form conspicuous hills, which are in some cases volcanoes only recently extinct.

Three other districts further west where gneiss crops out at the surface, will be noticed later.

The hill-ranges of gneiss commonly trend from north-north-west to south-south-east, a direction parallel to the foliation of the gneiss and to one of the sets of joints which traverse it. They rise with almost precipitous sides to heights of from 1,000 to 2,000 feet above the surrounding plains. In addition to the hill ranges, there are many peaks and isolated rocks of various heights dotted about the plains. These 'monadnocks' form a characteristic feature of the scenery in the arid or semi-arid gneissic region of Africa.

(b) The gneiss is a coarse-grained metamorphic rock, which has undergone total recrystallisation, whilst buried at great depths in the earth's crust. The crystalline grains, of which it is composed, tend to be of uniform size. There is no recognisable order of crystallisation, as in a granite, but each grain interferes with its neighbour's proper development of form.

The gneiss has frequently been referred to as 'gran--ite' by travellers, but throughout the district traversed no granite was met with, nor indeed was there found any igneous rock intruded into the gneiss, unless the veins of pegmatite can be claimed as igneous intrusions.

The gneiss is usually well foliated, the bands rich in darker constituents forming the smaller portion of the rock but sometimes they predominate. The chief con--stituents are quartz, felspar (mostly acid plagioclase and microcline) hornblende, and biotite. Other common minerals, abundant in certain localities, are augite, muscovite, garnet, magnetite, and calcite, and, in very small quantities, graphite, zircon, apatite, scapolite, rutile, tourmaline & sphene.

(c) One of the commonest varieties of gneiss is a pale rock consisting of a quartz-felspar mosaic speckled with flakes of black mica and hornblende. The darker bands in the rock, which are often present in small amount only, consist largely of biotite and hornblende with smaller quantities of felspar and quartz. This variety is well seen at Maungu. It has sometimes been mistaken for a sandstone by travellers.

The hills around Voi, including the Sagala and Ndi Hills consist of gneiss[1] in which the dark constituent is generally hornblende associated sometimes with augite, sometimes with biotite. Garnet in small crystals of a port wine tint is a common constituent of the gneiss. In the dark coloured bands, which are seldom more than a foot thick, it builds large crystals half an inch or more across, but it contains many inclusions of other minerals.

The gneiss[1] is traversed by many veins and strings of coarsely crystalline pegmatite, which consists chiefly of quartz and felspar. Mica is sometimes present, but only in small scales not more than an inch in diameter. The veins ramify through the gneiss and frequently anastomose, whilst their crystals interlock with those of the country rock. All gradations between normal pegmatites and pure quartz veins may be found. It is probable that the pegmatites were not intruded from below as offshoots of a plutonic magma, but originated during the latter stages of metamorphism of the gneiss by some leaching process.

In some of the more quartzose pegmatites, garnet is abundant and magnetite often occurs in scattered crystals along certain bands of the more quartzose pegmatites. An analysis of the magnetite made at the Imperial Institute gave the following results:-

	per cent.	
Ferric oxide (Fe_2O_3)	66·98	Equal to 66 % of
Ferrous oxide (FeO)	21·01	metallic iron.
Manganous oxide (MnO)	0·26	
Lime (CaO)	0·58	
Baryta (BaO)	0·62	
Magnesia (MgO)	0·23	

Titanium dioxide (TiO_2)	8·70	equal to 5·2 per cent of titanium.
Silica (SiO_2)	1·42	
Phosphoric anhydride (P_2O_5)	0·03	equal to ·013 per cent of phosphorus
Sulphuric anhydride (SO_3)	0·02	equal to ·008 per cent of sulphur.
Combined water (H_2O)	0·55	

The high percentage of titanium points to an admixture of ilmenite, whilst the silica is due to included quartz. The magnetite has been found in small quantities over a very large district. Walker reported its occurrence at many localities between Taveta and the Mzoni Mountains, but it has not yet been found in sufficient quantity to repay working as an iron ore.

A white or pale bluish-grey coarse crystalline marble is involved in the gneissic series. It is exposed along the Voi-Taveta road from a point about 2½ miles south of the Railway crossing to beyond the Voi River. Walker also reported its occurrence further to the south between Bura and Taveta. In a north-north-westerly direct-ion a similar marble was found a short distance west of the Railway at mile 186/5 (N. of Tsavo Station) and a large outcrop is crossed by the line about half a mile south of Kenani Railway Station. At the latter locality scales of graphite are scattered in bands through the limestone and the neighbouring gneiss. Much further to the north, but along the same line, Walker reported a similar limestone in the Kitui district. In the outcrops examined it was too coarse in the grain to have any value as an ornamental stone. It is, as a rule, very pure and produces a 'fat' lime on calcination.

Between Kenani and Kibwezi the numerous cuttings on the Railway show gneiss traversed by pegmatite and quartz veins. The Kyulu Mountains situated south-east of Kenani are reported by Gibson to be volcanic, whilst the Ongalea Mountains, situated south-west of Kibwezi appear to be partly volcanic, partly of gneiss. On the north-east side of the Railway the rectangular features of the Ndimgu & Yatta Plateau, which rises up immediately beyond the Athi River forms a striking contrast to the irregularly curved outline of the gneissic hills. Gregory and Walker refer it as a lava-capped plateau, which stretches in a south easterly direction some miles beyond the junction of the Athi and Tsavo Rivers and to the north-west it [nepheline-phonolite] appears to be continuous round the bend of the Athi River with the lavas of the Nairobi district. Though sometimes only three or four miles wide, its length is about 170 miles, and it was probably erupted through a fissure parallel to its length.

Between Kibwezi (mile 195/14) and a point on the Railway near mile 198, the gneiss is overlain by an olivine-basalt lava of no great thickness. Its surface is very irregular and is covered by dense forest. The basalt is very vesicular and traversed by regular joints. A small stream issues from its base at Kibwezi.

Gneiss again appears at the surface beyond mile 198 and forms the bedrock of the country around Makindu and for some miles to the north-west.

From near mile 215 to beyond mile 250 the Railway traverses a plain flooded by olivine-basalt lava, from which rise several small volcanic craters to the south of Simba Railway Station.

The higher hills in the neighbourhood of Sultan Hamoud are composed of gneiss. This rock also forms the country rock on both sides of the railway as far as mile 293, where it passes beneath the lava-plains of Kapiti. It continues at the surface in a northward direction and forms the hills called Mua and Ulukenia, which bound the plains on the east. The gneiss of Mua and the Kiu district is a pale coloured rock ~~containing~~ consisting of quartz and felspar, with small quantities of muscovite, biotite, magnetite and zircon. It is traversed by numerous veins of pegmatite and quartz.

Gneiss appears to occupy the whole of the Machakos district eastward to the Athi River and northward to the neighbourhood of Donyo Sabuk, where it is overlain by the volcanic rocks. It appears at the surface again in the big elbow bend of the Thika-Thika River and also in the neighbourhood of Fort Hall.

(d) The Fort Hall 'boma' stands on the edge of a ~~small~~ small area of gneiss, which stretches north and north-east to Tana River. The gneiss is similar to that already described. To the west and south-west of the 'boma' the gneiss passes beneath volcanic rocks. That the latter have been erupted on an irregular land surface of gneiss similar to the hilly country, which it forms to-day, is nowhere better illustrated than here. Not only is the boundary a very irregular one, but amidst the volcanic rocks there appear small areas of gneiss which represent the tops of buried hills now being laid bare again by denudation of the vol-

-canic rocks. Several such patches of gneiss were noticed on the Fort Hall-Nairobi road in the Kathamba and Maragua valleys, & along the course of track north of Fort Hall in the direction of Nyeri

(e) The huge fault-scarp of Elgeyo on the west side of the Rift Valley consists of rocks of the Volcanic Ser--ies resting on an irregular surface of gneiss, which crops out in a narrow band along the base of the scarp. Walker reported the occurrence of eclogites here, in addi--ion to the commoner varieties of gneiss.

(f) West of the Rift Valley the gneiss appears from beneath the Volcanic Series in the neighbourhood of Muhur--oni. Along the Railway it is first seen at mile 541/14 and crops out at intervals as far at least as mile 548/9. Beyond this point, the black cotton soil completely ob--scures the underlying rock. The gneiss is a pale gray or pinkish banded rock consisting of quartz and felspar with a small amount of mica in thin lenticulat bands. Around Muhuroni (mile 547) the conical hills and irregular surface of the area occupied by gneiss contrast strongly with the flat-topped terraces hills of the Volcanic rocks.

(2) Superficial Deposits on the Gneiss.

(a) The Red Earth.
(b) Limestone (kunkar)
(c) Effect of destruction of native forest.
(d) Minerals of value.
(e) Black cotton soil and kunkar.

(a) The most widely spread superficial deposit in the gneissic region is a bright red sandy earth, which mantles the plains and the base of the hills. As seen from the summit of one of the latter it appears to be absolut--ely flat, but it rises appreciably around the base of the hills, where it forms gently graded cones, which lead up to some stream-course or depression in the hills.

The red earth is formed entirely by the decomposition and disintegration of the gneiss. The felspar, hornblende and augite are the constituents, which decompose most read--ily and form a clay stained bright red by ferric oxide. Their decomposition brings about the disintegration of the gneiss. The mineral constituents, which do not read--ily decompose, such as the quartz, magnetite and garnet are broken up and mixed with the red clay. Thus, on the plains a fairly uniform deposit of red earth, which is distinctly gritty to the touch, has accumulated sometimes to a great thickness. The bore at Mackinnon Road Station proved it to be 63 feet in depth. The site of the bore is near the edge of one of the numerous hollows which trend from south to north across the Taru Plain. On the ridges, which separate the hollows, the gneiss occasionally comes close to the surface, the red earth being only a few feet thick. A top layer twoto four feet thick is often more sandy and porous than the underlying red earth, and is due to the leaching action of the rain in washing out the finer clayey particles and carrying them down to lower levels.

(b) The accumulation of limestone nodules, known by the Indian name kunkar, is frequently found at a depth of a few feet in the red earth. It is sometimes the most easily accessible material for ballasting the line or for top-dressing red earth ballast to keep down the dust. It was noticed that the largest deposits occurred on sloping ground just above the surface level of the neighbouring hollows. Its origin explains its apparently erratic distribution. Small quantities of lime are set free during the decomposition of the plagioclase felspar, hornblende, &c. of the gneiss. It is dissolved by the percolating rain-water containing carbonic acid and is carried downwards. Solar evaporation succeeding the rain, dries the surface. Much of the water reascends by capillarity and is evaporated both on and beneath the surface. During this process the carbon dioxide is lost and the lime deposited. The downward percolation of the rain is checked at the base of the top sandy layer by the less pervious earth below, so that the water tends to flow laterally along the junction towards lower ground. At the same time the process outlined above takes place and the lime is deposited chiefly towards the lower end of the slopes, e.g., at miles 72 and 77.

The lime nodules may become cemented into a bed of limestone, such as is worked at Makindu. An analysis of this limestone made at the Imperial Institute gave the following results:-

	per cent.
Lime (CaO)	47·50
Magnesia (MgO)	2·90
Carbonic Dioxide (CO_2)	33·63
Ferric Oxide (Fe_2O_3)	2·58
Alumina (Al_2O_3)	3·00
Phosphoric Oxide (P_2O_5)	0·50
Residue insoluble in acids, chiefly silica (SiO_2)	7·63
Moisture and combined water.	2·42
	100·25

The impurities are due to the inclusion of small quantities of red earth. On calcination the kunkar yields a lime which is found suitable for ordinary building pur-poses.

(c) In places where the dense indigenous forest cov-ers the red earth, it is uniform throughout its whole depth. The kunkar is then found in lenticular patches at, or close to, the junction with the underlying rock. If for any reason the forest is removed from a natural slope, the rain carries off the red earth, and leaves an almost bare surface scattered over with lumps of quartz and magnetite, whilst the kunkar is left in mounds up to 4 or 5 feet in height and 10 yards in diameter. Several small areas in the neighbourhood of Voi have been ruined in this manner, a particularly good example being seen half a mile north -west of Voi Railway Station. Whilst the natural forest is rich in Sansivier*a* and other valuable plants, the ground stripped of its sub-soil can support only 'wait-a-bit' and other thorns. It is another example of the irreparable dam-age caused by the careless destruction of forest.

There can be no doubt that the red earth would be exceedingly fertile under suitable irrigation. When a permanent stream reaches it, the water is sooner or later absorbed, and thus naturally under-irrigates a certain tract of land. The area naturally irrigated is, however, small and is usually occupied by the few native plantat--ions, which occur upon the low ground.

On the hills the decomposition of the gneiss takes place more by disintegration of the surface under atmos--pheric changes than by decomposition of its constituents. The torrential rains carry down the disintegrated material and spread it out in thin sheets around the base of the hills. The heavier minerals, viz, the magnetite and garnet with some hornblende augite, zircon, &c. are concentrated in the ephemeral stream courses, whilst the lighter min--erals may be carried out a mile or more from the feet of the hills.

The examination of the heavy residues has not result-ed in the discovery of any of the rarer marketable min--erals. Though there are large areas of gneiss, which have not been prospected, few minerals of economic value have been obtained from it up to the present. Those which have been reported have not been found in the requisite quantity or condition. Building material is at present in great demand. The use of the kunkur as a source of building lime has already been noticed. In the Nairobi and Rift Valley districts, where most of the building is now going on, the rocks are not capable of yielding a satisfactory sand, but the decomposition of the more quartzose bands in the gneiss produces a sand, which when washed in the nullahs is clean and sharp. The localities where a good sand can be obtained nearest to the above-named districts are Kiu on the east and Muhoroni on the west. Although Machakos

Road Station on the east is on gneiss and nine miles nearer Nairobi, the nullahs are too steeply graded to let the sand lie. It is washed down towards Kiu.

(e) The black cotton soil covers only relatively small areas in ~~the~~ that part of the gneissic region traversed by the Uganda Railway. It will be described more fully in treating of the sub-soild of the volcanic regin, where it spreads over vast areas. Here it will be sufficient to state that it is found only on ground, which is poorly under-drained on account of an impervious rock-floor and liable to collect water during the rains. The chief areas where this sub-soil is found near the Railway are in the gneissic region, are (1) the low ground near Makindu, (2) the low-lying land near Sultan Hamond, (3) the plains around Kibigori. Of these the last named is the most im-portant tract from an agricultural point of view.

The black cotton soil also forms terraces along the banks of the streams, especially beside the more permanent rivers flowing in a gently graded valley, e.g., the Voi River. A bed of kunkar is commonly found beneath the black soil along the edge of the stream-course. Its origin is similar to that of the kunkar in the red earth already described. The lime is dissolved by the rain-water percol-ating down towards the streams. The black cotton soil is retentive of moisture and becomes more or less water-logged during the wet seasons. As the water-seeps out into the river channels, the carbon dioxide escapes and the lime is deposited.

Water Resources in the Gneissic Region.

Supply from deep wells. The gneiss is essentially a non-porous rock and cannot hold water except in the minutest quantities. Whilst most of the rain falling on the hills of gneiss either runs off or is evaporated, a small portion does find its way down joints, cracks, and fissures, and issues in springs at a lower level on the hill side. Water, however, is required on the plains, and here it is probable that the joints and fissures contain no appreciable quantity of water. In the Mackinnon Road bore several joints and fissures were passed through, but no water was found. Further, it must be remembered that the chances of striking water-bearing cracks in an ill-watered country subject to intense solar evaporation are exceedingly small, and that artesian wells cannot be expected. It has been suggested to me that a line of deep bores should be made in the neighbourhood of the Railway between Escarpment and the east end of the Taru Plain. So far as the line between mile 283 and the east end of the Taru Plain is concerned, it is highly probable that none of them would be successful, but, if one or more did strike water, the amount that could be pumped would be small, the benefit of which would probably not compensate for the cost of boring.

Supply from shallow wells. The success of shallow wells on the Taru Plain in the neighbourhood of the Railway is but little more hopeful than that of a deep well. The most favourable sites for shallow wells in the superficial deposits are in the hollows on either side of Maungu Station. These hollows receive the water draining off the sides of Maungu Hill. The portion which sinks deeply into the red earth, must seep away northwards towards the de-

-pression, which runs from Voi towards Kilifi. A well sunk to bed-rock in the floor of one of these hollows would in--tercept some of this seepage water. The supply might be ~~sufficient~~ sufficient for the station and the neighbouring landy, but it might fail towards the end of the dry season. The construction of an 'underground dam' to inter--cept this seepage water (supposing its presence proved) would cost the Railway far more than the present method of running water-tanks on the trains, so that it may be left out of account until a scheme of irrigation for the Taru Plain be under consideration.

Several attempts have been made to obtain water from wells sunk in the red earth, more especially in the Taru Plain. The attempts have been uniformly unsuccessful, and in most cases the reason is clear. About one mile east of Mackinnon Road Station a small patch of black clay soil containing pools of saline water stands in a slight hollow on the top of a low ridge. A well sunk beside it reached gneiss at a depth of a few feet, but naturally no more water was obtained. The presence of the swamp is due to the said rock lying close beneath the surface and holding up the water, which has become saline by continued evapora--ion. The action of the alkaline salts has, as is usual, turned the soil black. For the same reasons, water is found beside the railway at mile 57, but no further quantity would be obtained from a well at that place. The well at mile 58/10 often holds water for a similar reason. The well at Mackinnon Road Station was not sunk deep enough to test the presence of seepage water near the base of the red earth.

III. THE VOLCANIC REGION.

1. General Description.
2. The Rocks of the Volcanic Region.
3. Detailed Description of the Volcanic Region.
4. The Superficial Deposits of the Volcanic Region.
5. Remarks on the Water Resources.

1. General Description.

The region underlain by volcanic rocks includes all the central and much of the western parts of the Protectorate. South of latitude 1° N. the volcanic rocks occupy an area which can scarcely be less than 24,000 square miles. This area includes all the 'Highlands' at altitudes of 5,000 feet and upwards, where the climate is comparatively cool and most suitable for European colonisation.

The volcanic region is traversed from north to south by the great trough of the Rift Valley, on each side of which the ground rises in one or more precipitous scarps. The crests of the topmost scarps form lines of high ground, which reach elevations of from 7,000 to 9,000 feet above the sea. From the crests of the scarps the ground sinks gradually on the west to the basin of the Victoria Nyanza, and on the east to the Kapiti and Athi Plains.

The broad physical features are based on a geological structure, which is simple in its outline. Both the eastern or Kikuyu and the western or Nandi slopes are built up of a succession of lava-flows and volcanic tuffs, which dip in each case with the slope of the surface. The average angle of dip, however, is less than the average slope of the surface, so that as we ascend from the east or from west to the edge of the Rift Valley newer and newer rocks are encountered. This structure has an important bearing on the movements of underground water (Section 4 5).

If the edges of the beds exposed in the scarps of the Rift Valley be prolonged in imagination until they meet, the volcanic rocks would form a broad arch some 130 miles across. This arch is broken by the Rift Valley, which has been regarded since the publication of Professor Suess' Memoir in 1891, as a strip of sunken country. The keystone, as it were, of the arch has fallen in, whilst the neighbouring voussoirs have slipped down, but not quite so far as the keystone.

The chief faults which bound the subsided strips of country are not actually seen in section. Perhaps the best proof that the scarps are fault-scarps, and not features due to denudation, is that the crest of a scarp does not follow one particular lava, but that the beds run obliquely across the face of the scarp. Long lines of cliff, which cut obliquely across a series of soft and hard beds, must be either fault-scarps or sea cliffs; and the latter interpretation is out of the question in this case. Details of the structure of some fault-scarps at Naivasha are given in section 3 c .

The subsidences doubtless took place slowly and were protracted over a lengthened interval of time. Evidence for this is afforded by the system of river-drainage in the case of the Laikipia scarp and is discussed in section 3 e . I have not been able to follow out all the sub-divisions of the volcanic series proposed by Prof Gregory in his book 'The Great Rift Valley', but there are clearly two phases of vulcanicity, the earlier of which is, on the whole, older, whilst the later is, on the whole, younger than the subsidences. It cannot, however, be assumed that whilst the earth-movements were taking place, volcanic action was dormant.

The eruptions which poured forth the earlier lavas belong to the 'plateau' or 'fissure' type. The liquid magma welled up through fissures, and it would appear that no craters were formed. The predominance of certain types of lava in particular districts, e.g., basalts between Lake Baringo and Lake Hannington, and the abundance of a particular kind of trachyte between Kijabe and Kikuyu suggests that there were a number of centres each of which usually poured forth its own kind of lava.

The vulcanicity which followed the subsidences of the Rift Valley, was manifested by the formation of cones with craters. The largest of these volcanoes in the Rift Valley are Lerasgut, Suswa, Longonot, Eburu, Menengai, and Eldalat, whilst a host of smaller cones rise from the plains on the east side of Lake Naivasha and to the north of Eburu. On the eastern wall of the Rift Valley, Doenyo Lamayu, near Kikuyu; Kibibieri, near Naivasha; Nandarua and the heights of the Aberdare Mount--ains; are probably all the denuded remnants of a series of volcanic cones built up on the plateau-lavas.

Altogether east of the Rift Valley, the cone type of vulcanicity is represented by the snow-capped giants, Kenya and Kilimanjaro; the volcanic line of the Kyulu and Ongalea Mountains; and the small denuded cones which dot the plains on the west and south-west of Kenya.

The remarkable perfection of many of the craters in the Rift Valley testifies to the late geological date of the eruptions, but the freshness of the cones is in part due to the relative aridity of the climate. The phenomena, which usually accompany the dying phases of vulcanicity, are represented by numerous 'fumaroles', which constantly emit clouds of steam. A line of fumaroles issues along the course of a 'comendite' dyke in the Enjorrorrua valley south of Naivasha. The rocks beside the vents are more or less silicified and contain small quantities of iron sulphides. Other fumaroles occur on the northern flanks of Eburu and near the railway at mile 417. The issuing steam seems to be quite pure. Warm springs are known in the Kedong Valley and at Maji Moto near the northern end of Lake Hannington. A copious spring, charged with gas, which is mainly if not entirely, carbon dioxide, issues in one of the small valleys at the head of the Ndo Valley (Kamasia). In the Kedong Valley, a 'mofette' commonly known as the 'stink-hole' emits a gas, which is said to be poisonous, but I am not aware that its nature has been proved.

Whilst there is abundant testimony of active volcanicity in geologically recent times - indeed, a volcano situated near the south end of Lake Rudolf is said to be active yet - the age of the older plateau-lavas remains unknown; but various reasons have been advanced for believing them to be of Tertiary age, or at any rate not older than the Upper Cretaceous. The only fossils known from the volcanic rocks are the bits of fossil wood in volcanic tuffs at Fort Ternan railway station, and on Rusinga Island (Victoria Nyanza); but they are too poorly preserved for determination.

Although a vast interval of time must have elapsed between the formation of the gneiss and the earliest volcanic eruptions, there is no evidence that any other formation lies between the volcanic rocks and the gneiss in the region east of the Rift Valley. West of the Rift Valley the same statement holds good for the districts neighbouring the course of the Railway, but there are records from the Nandi and Semia Hills of another formation consisting of quartzites, phyllites, and ferruginous schists, which appear to be identical with the Karagwe series of Uganda (See Scott-Elliot and Gregory; and Baleeri). The Karagwe Series lies between the gneiss and the volcanic rocks, but it has only a limited extension beneath the volcanic rocks of East Africa.

2. The Rocks of the Volcanic Region.

The rocks of the volcanic region comprise (a) lavas, (b) tuffs and agglomerates and ashes, (c) interbedded sedi-ments, (d) dykes.

(a) The lavas preponderate over the other kinds of rock. They occur in nearly horizontal sheets, commonly from 20 to 40 feet thick, though some of them appear to be over 100 feet in thickness. They exhibit all the characters usually found in lava-flows. The upper and under surfaces are vesicular and sometimes 'ropy'. The vesicular crust on the upper surface is sometimes 3 or 4 feet thick, and the vesicles may be filled with zeolites, calcite, chalcedony, opal, or white clay. The yellowish 'flints' found in the soil are amygdules set free by decomposition of the lavas. Flow-structure is sometimes well developed, and may be due to a parallel orientation of the mineral constituents, as in the trachytes, or to slight differ-ences in the composition or structure of contiguous bands in the rock, as in the rhyolites. Though the jointing is usually of the ordinary 'cuboidal' kind, a jointing into hexagonal columns is found in the middle parts of some lavas, more particul-arly of the basalts. The lavas seem to have been erupted one after another without any great lapse of time between the out-pourings; at least it is very rare to find evidence of the weathering of a flow, before it was covered by the succeeding flow.

Although there are many varieties which grade into one another, the lavas may be divided into (α) basalts, (β) nephelinites, (γ) phonolites (δ) trachytes, (ε) rhyolites. Dr G. T. Prior has given a very full account of the microscopic petrology of these rocks in the mineralogical magazine for 1903.

(α) The basalts are black or nearly black rocks. The fine-grained matrix of which consists of plagioclase felspar, augite, and magnetite. In this base, there are usually scatter-ed large black crystals of augite, smaller ones of olivine, and in some rocks large crystals of plagioclase felspar.

Though widely distributed, they occur abundantly in certain districts and are almost unrepresented in intervening tracts. They form the greater part of the scarp east of Lake Baringo, and are common in the hills between this scarp and Lake Hannington. Most of the lavas between the Engurol and Nauga Rivers, which cross the track from Nyeri to Rumuruti are basalts.

(β) The nephelinites are heavy dark greenish-black rocks, which were found only along the course of the Railway on both sides of Lumbwa and Fort Ternan Stations. The fine-grained base consists of nepheline, augite and magnetite, and through it are scattered phenocrysts of augite, and usually some of nepheline. In some varieties olivine appears, in others melil-ite and perofskite. They are generally a good deal decomposed near the surface.

(γ) The Phonolite is the most widely distributed, if not the most abundant type of lava, and occurs in several varieties, which have been described by Dr Prior. In colour they are dark grey, or brown, sometimes almost as dark as the basalts, but they are not so heavy.

A fresh surface of the rock usually shows large crystals of alkali-felspar, sometimes greasy brownish crystals of nepheline and small crystals of augite in a fine-grained groundmass, which microscopic examination shows to consist of nepheline, alkali-felspar, catophorite, cossyrite, aegirine, augite, apatite, magnetite, and an isotropic mineral, probably sodalite or analcite.

(8) The trachytes are paler coloured than the phonolites or basalts, being of greenish, bluish, or yellowish grey colour. The greater part of the rock consists of small sanidine felspar crystals, amongst which are minute grains of aegirine, augite and sometimes catophorite and cossyrite. Generally they contain porphyritic crystals of alkali-felspar.

The surface is rough and harsh, and the fracture glistening. They exhibit a good flow structure, which is due to the parallel arrangement of the felspar crystals. A closely-spaced, platy jointing, parallel to the flow-structure, causes the rock to split readily into slabs, but it does not break at all easily across the flow-structure. When the flow-structure and platy jointing are curved, the rock is very difficult to quarry and dress, as in the case of the rock of Nairobi Hill. If used for macadamising roads, they break down to a powder, which does not bind, and leaves the roads dusty in the dry seasons. The trachytes contain numerous small 'miarolitic' cavities, but this porosity does not increase their water-transmitting powers, because the cavities are not in communication with one another, but are separated by partitions of rock as impervious as an ordinary lava.

There are several varieties of trachyte, one of which closely resembles phonolite, whilst others contain quartz in the base. The majority of the lavas exposed along the Railway between the outskirts of Nairobi and Kijabe Station are of the latter type.

(7) Rhyolites. Under this name may be classed a number of dull green rocks which contain a few phenocrysts of alkali felspar (sanidine and anorthoclase). Their chief characteristic is a streakiness, which is marked by lenticles of black glass (obsidian), alternating with bands of greenish

glass which is more or less devitrified. Since they frequently contain numerous bits of lava and pumice, they may be mistaken for tuffs.

These rocks are fairly 'soft' when freshly quarried, but harden considerably on exposure to the sun. They split with-out difficulty in any direction, so that they are easily dressed to shape. They have been used by the Public Works Engineers in the construction of buildings at Naivasha and Fort Hall. In the natural outcrops, they weather well, and form prominent features on a hill-slope, e.g., the line of crags on the south side of Mathioya valley, immediately east of Fort Hall, and the crags north of the Maragua bridge on the Fort Hall road. The rocky features on the scarps east of Gilgil Railway Station are, in many cases, outcrops of rhyolite. This rock also forms the sill of the waterfalls on the Ruiru and Chania Rivers in the Kikuyu District.

Under the rhyolites must be placed some crystalline rocks, called 'comendites'. These are pale yellowish or grey--ish rocks consisting of a fine grained base of quartz and fels--par, throughout which are scattered ill-defined spots of a dark mineral, which is generally riebeckite. Phenocrysts of quartz and sanidine felspar are also present.

These rocks are not common in East Africa. They form lines of crag in the Tigrish valley about 2½ hours march below Eldama Ravine 'boma', and they also occur in the valley (Enjororowa) south of Lake Naivasha.

Obsidian and pitchstone are found in the Rift Valley amongst the lavas, which have been erupted from the later vol--canoes, e.g., Eburu and the smaller craters which are to the east of Longonot, but they are rare amongst the lavas, which form the plateaux and fault-scarps. Their composition has been shown by Dr Prior to correspond to that of a phonolite in some cases, to that of a rhyolite in others.

(b) Tuffs and agglomerates are found interstratified with the lavas of the fault-scarps and plains. They consist of fragments of lava, broken crystals and microlites of the minerals, which occur in the lavas, and altered bits of pumice. The lava fragments are generally quite small, but in the agglomerate, which is seen in many of the railway cuttings between Lumbwa and Muhoroni there are huge blocks weighing many tons. The agglomerates near the base of the volcanic rocks contain lumps of gneiss, and those on Rusinga Island contain blocks of granite.

The finer tuffs are usually more or less stratified and of a greenish colour, but weather readily to a pale grey or yellow colour.

The volcanoes of the Rift Valley, more especially the smaller cones are largely composed of a greenish-grey volcanic ash. The ash has also been blown considerable distances during the eruptions and is found mixed with sub-soil and banked up against the fault-scarps in several places. The banks of pumiceous 'lapilli', which are seen in the neighbourhood of Gilgil, have had a similar origin. They lapilli are used for gravelling the station platform.

A very white pumice in lumps from 2 to 4 inches long forms terraces 10 feet or more in height at the bottom of the gorge, about 7 miles south of the south end of Lake Naivasha.

(c) Beds of sedimentary origin are not of frequent occurrence in the volcanic region. They consist of partly con-

-solidated sand and fine gravel, and sometimes of greenish mud--stones, or white thinly-laminated shales. Details are given in describing the localities where they were found, viz., Naivasha, near Gilgil, on the scarp east of Lake Hannington, in the Kào Valley (Elgeyo) &c. These sediments by the amount of dip of their bedding planes give the most reliable evidence of the nature of the earth-movements which have affected the volcanic region.

(d) Intrusive rocks are rare in the volcanic region. No sills were met with and only a few dykes. The latter seem to be limited to the neighbourhood of the later volcanic cones, and are not orientated in a common direction. They are usually closely related in petrographical character to some type of lava found in the neighbourhood. A pebble of coarse-grained nepheline-syenite found in the bed of the River Loldama, which crosses the track between Nyeri and Rumuruti, points to the occurrence of that rock on the eastern flank of the Aberdare Range.

3. Detailed Description of the Volcanic Region.

(a) Kapiti and Athi Plains.

(b) Nairobi Township.

(c) Kikuyu District.

(d) Kiambu, Fort Hall, Nyeri, Rumuruti.

(e) Eastern Flank of Rift Valley.

(f) Western Flank of Rift Valley.

(g) The Nandi Slope.

(a) The Kapiti Plains from the edge of the volcanic area (mile 283) to the neighbourhood of the Athi River (mile 310) is under-lain by a phonolite containing large crystals of felspar and nepheline. In the bed of the Athi River another phonolite appears beneath it, whilst in the scarp north-west of the River other lavas come on above and continue beneath the Athi Plains to the outskirts of Nairobi.

(b) The Township of Nairobi. is defined by the circumference of a circle, which has a radius of 1½ miles. The central, eastern and southern eastern districts are relatively low-lying, being, in fact, a portion of the Athi Plains. In the south-west and west, the ground rises abruptly to the higher plateau of Nairobi Hill, whilst on the north, it rises with an easier gradient to the district called Parklands.

Within this area four distinct beds of rock crop out at the surface. These are in descending order -

(4) Trachyte.

(3) Agglomerate.

(2) Clay-stone (grey building-stone)

(1) Phonolite.

(1) The lowest rock is a nearly black porphyritic phonolite, which crops out on the low ground south of a line drawn through the Railway Stores and the south-west end of the Railway Offices. It also appears on both sides of the Nairobi River from the township boundary upwards to a short distance above the bridge on the Kiambu Road. It lies directly on the phonolite of the Ngong River and these two lavas were pierced in the chisel bore which was put down in the yards of the Rail--way workshops toa depth of 100 feet. Though difficult to break, it is likely to prove more satisfactory than the other local rocks for metalling the roads in Nairobi.

(2) Overlying the phonolite is a pale grey, soft, porous stone about 12 feet in thickness. It is largely used as a building stone in Nairobi, on account of the ease with which it can be quarried and dressed into blocks. It is so porous that, when a dry piece is dropped into water it causes an effer--vescence; but no inconvenience has been found to result from this porosity, ~~probably~~
No trace of flanking or cracking was noticed even on the old--est buildings, but there is sometimes slight discolouration. On account of its 'softness', it would be risky, if not danger--ous to use it in the construction of a high building.

The rock contains small scattered phenocrysts of sani--dine felspar, but the groundmass is altered to a clay, in which are numerous small cavities like those in the trachytes. At its edges the rock becomes more compact, slightly vesicular, and shows a faint banding, but the mass of the rock is quite homogeneous and shows no signs of bedding. It seems to have been a lava, probably glassy in part, ~~but nearer the trachytes in composition~~, which has undergone a pocess of alteration similar to 'kaolinisation'. Similarly altered rocks have been termed 'clay-stone', a name which seems quite appropriate to the rock under description.

Its outcrop in Nairobi may now be noted. From the quarries on the eastern side of the Nairobi River near the township boundary, the outcrop trends in one direction to the north-east, but passes outside the township before reaching the Race Course. In the other direction, it runs parallel with the Nairobi River, but after passing below the Mohammedan cemetery, it turns towards the north in the direction of the western corner of the Race Course. Its further outcrop in this direction appears to be checked by a fault, which throws the bed down below the level of the Nairobi River. The fault pro--bably crosses the River about 100 yards above the bridge on the Kiambu Road and trends in a N.N.E. to S.S.W. direction. The fault was not actually seen, but the sudden change in the beds is most easily explained by its aid. On the western side of the Nairobi River the outcrop of the clay-stone can be follow-ed from a point on the Kiambu Road about 400 yards south-west of the bridge, in a south-easterly direction, through the quarries below the Railway landies as far as telegraph pole 3/4/9. Here the outcrop swings round sharply to the west-north-west, and passes beneath the carriage sheds and the railway station platform. It continues in the direction of the bridge near the Episcopal Church, but its exact outcrop was not seen here. The outcrop, however, must cross the stream and run south-wards along the foot of the hill below the cemetery. The springs along this line are pobably due to water escaping from the clay-stone and the overlying agglomerate.

A bed of the clay-stone is opened up in a quarry close to Ainsworth's Bridge. It is probably the same bed brought up to the surface by the south-easterly dip of the strata. Its outcrop was followed a few hundred yards up the Garu River. In a south-easterly direction it disappears beneath