Short Paper No. 5.

GEOLOGICAL SURVEY DEPARTMENT
TANGANYIKA TERRITORY

Water Supplies for Cattle along the Kondoa Irangi—Handeni Stock Route

BY

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PREFACE.

This Short Paper serves as a useful progress report of the results of the first field season's efforts of the newly-established water supply section of the Geological Department, and Mr. Wade is to be complimented on the useful amount of work accomplished during the short period since the inauguration of the work.

The existing conditions in arid and semi-arid regions where primitive natives are concerned are a heritage of long-continued struggle against the uncertain and adverse climatic factors of these areas. They have allowed life of human beings and cattle to develop to a certain stage, often involving annual hardship, toil and detriment to health generally, especially to the infants.

A stage has been reached beyond which further increase in population, alleviation of suffering and development of the resources of the region can only advance by the improvement of the primitive insanitary and uncertain water supplies.

The requirements vary in degree from those of more advanced communities. The stage of civilisation, the customs, resources, standards and intelligence of the people occupying these areas determine that simple and not unduly costly schemes for both developing the supplies and of raising the water be introduced, and that they be multiplied as much as possible in order to serve many small centres over widely separated districts.

The time is not yet ripe for costly boring, nor for very large conservation schemes or irrigation projects. As development takes place, however, with response to outside guidance and stimulus, there will be a growing demand for larger and more comprehensive schemes for native requirements.

The Short Paper therefore deals with much preliminary work, in which an attempt has been made to ameliorate the hard lot due to recurrent water shortage. The scope and method of attack therefore are limited by the above considerations as well as the smallness of the staff and funds to deal with the vast area concerned.

E. O. TEALE,
Director.

GEOLOGICAL SURVEY DEPARTMENT,
DODOMA.

CONTENTS.

WATER SUPPLIES for Cattle along the KONDOA-IRANGI to HANDENI Stock Route.

F. B. WADE.

I.—INTRODUCTION.

At the instance of the Director of Veterinary Services a reconnaissance survey of this route was performed in 1927 by Dr. Teale, who confirmed the urgent need for improved water supplies for cattle driven over this route, and as a result of his investigations he made certain valuable recommendations The sum of £500 was allocated from public funds for putting his views into effect , and the writer, having charge of the newly-created water supply branch of the Geological Survey, was entrusted to expend this amount to the best advantage.

At many points along this route for a part of the year cattle are watered at rain ponds occupying depressions adjacent to it, and Dr. Teale favoured the deepening and extension of many of these to conserve more water for a longer period ; but with the funds in hand it was not possible to embark on costly schemes of this magnitude.

An official estimate of the number of cattle driven along this route per annum is 20,000, and they are principally absorbed, for slaughter purposes, by the plantation regions along the coastal belt of the Territory. At a conservative figure this traffic is valued at £50,000 per annum, and the amount actually spent during 1928 in an attempt to alleviate the trials to which this livestock is subjected from water-shortage amounts to less than 1 per cent. of this sum.

The importance of this route is becoming increasingly greater with the passage of time, since the demand for slaughter cattle is increasing with the economic development of the coastal belt, and the presence of tsetse fly and other cattle pests precludes the coastal regions from becoming self-supporting in this important commodity. A safe and easy corridor to the higher-priced coastal markets will also induce the cattle-owning natives of the interior to compete, and that this tendency exists is evidenced by the presence of a large herd of cattle belonging to more enlightened natives of the Nzega District seen on the road by the writer during the course of his work. This herd must have travelled on the hoof a distance of about four hundred miles to the market at Korogwe.

At present the cattle trade along this road is in the hands of Somali drovers almost entirely, and doubtless the lack of competition tends to maintain high prices for beef on the coast.

Although useful work was performed on parts of this route, it cannot be said that the water supplies along this route are adequate for present needs, and some endeavour to describe the work done and the difficulties to be overcome is attempted in the following pages.

ACKNOWLEDGMENTS.

The writer is indebted to many persons who contributed information and assistance in the field, and special mention is made of the Stock Inspectors at both Kondoa-Irangi and at Kibaya, Messrs. Emson and Gowan.

The Labour Supervisor at Karema River, Mr. J. Deacon, was also particularly helpful in supplying native foodstuffs cheaply and readily when they were needed by the parties working in the inhospitable, uninhabited regions in the plains round Kibaya.

Dr. Teale's notes, both geological and in connection with water questions, were of great value, but it was found that the existing maps of this route were lamentably incorrect, so the whole route was traversed afresh with magnetic needle and cyclometer and a new map prepared, which it is hoped will be of more value to the public. The surveying of this road, 186 miles long, was done by Native Assistant Mohammadi Zungufya, and plotted by the writer. Boring Foreman B. Waizeneker also mapped some of the country round the Kerelawa Mbuga during boring operations and his map is incorporated in the main map of the road.

The loyal co-operation of both Boring Foreman Waizeneker and Well Foreman Ellero in their respective fields of operation is placed on record.

II.—GENERAL DESCRIPTION OF THE AREA TRAVERSED BY THE CATTLE ROUTE.

The area described in this report lies in three different Administrative Provinces, namely, the Central Province, Southern Masailand and the Tanga Province. Administrative Offices are situated at each end of the road, *i.e.*, at Kondoa-Irangi and at Handeni. Both maintain post offices, but only Handeni is in telegraphic communication with the rest of the world.

The cattle route follows the main caravan road connecting these two centres, and the road is passable by motor traffic in the dry season, though in places it is little better than a cattle track.

The surface of the country is covered with scrub over most of its length, but has open patches, notably at its western end near Kondoa-Irangi, and grassy stretches in the Masai country in the plains to the west and east of Kibaya.

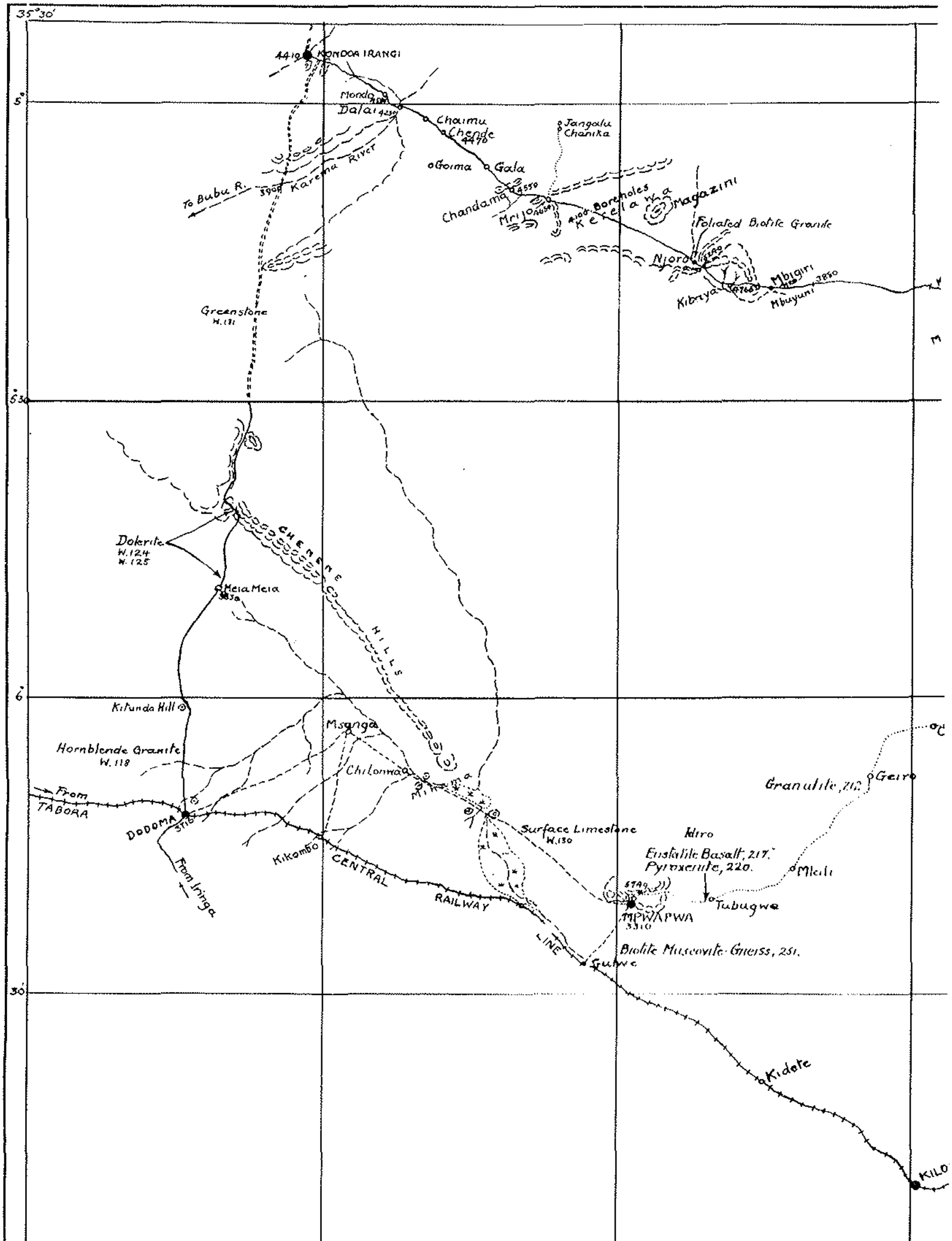
Population and its Distribution.

For a dozen miles east of Kondoa-Irangi scattered hamlets inhabited by Warangi natives are to be found. The succeeding 25 miles passes through thinly settled Burungi country, a few of whose villages are shewn on the map, and as the Masai country is approached the inhabitants of the villages become more mixed with alien natives, notably Wanyamwesi and Wanguu.

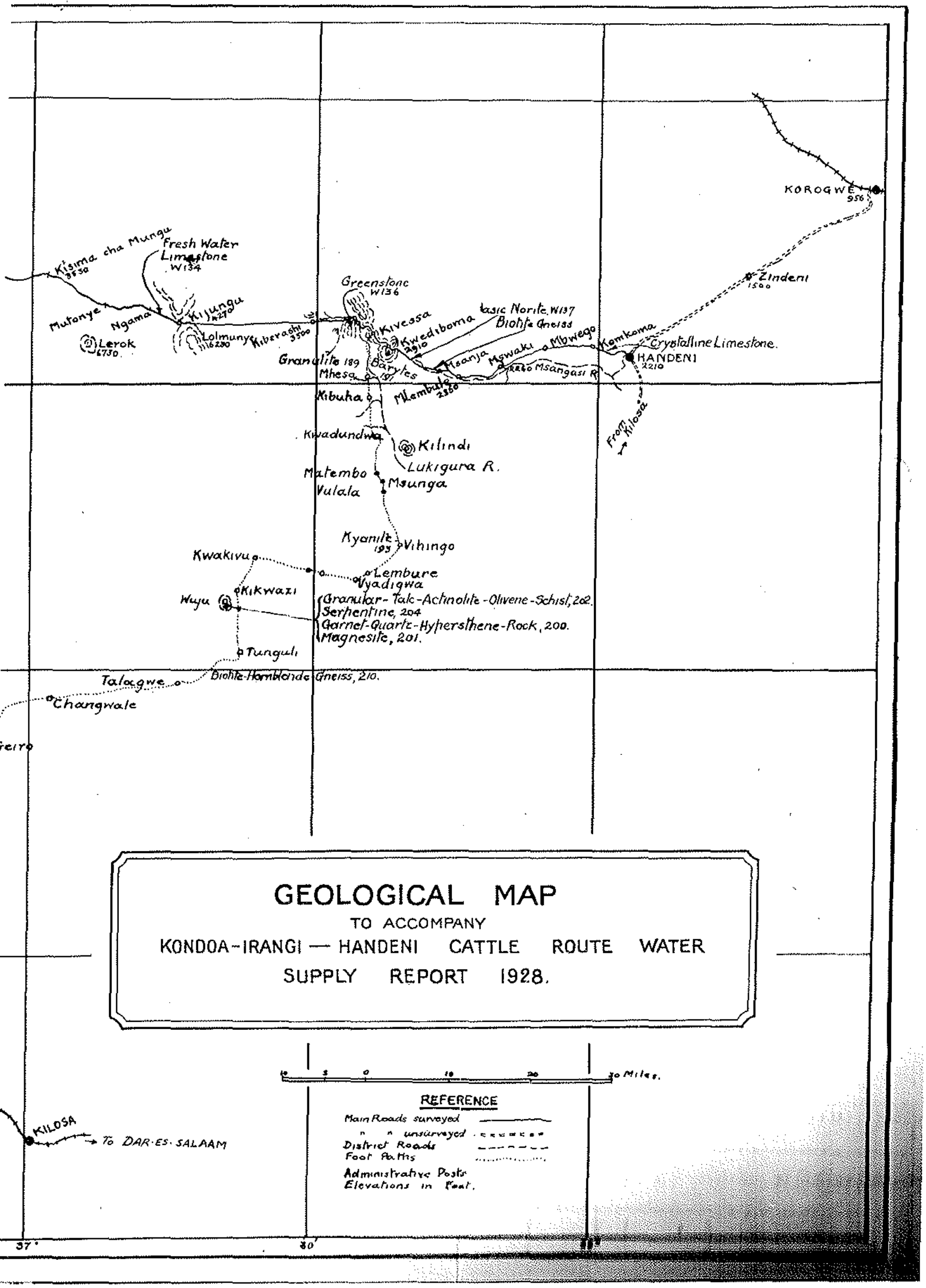
In Masailand the Masai are to be seen in encampments with their cattle and are more thickly concentrated round Kibaya, especially during the dry season. The few settled villages such as Njoro, Kibaya, Mbigiri and Kujungu are peopled by alien Wanyamwesi, Wasukuma and Wanguu. At Kibaya a Veterinary official is occasionally to be found and a cattle dip is established there and is used by both the Masai and the trade stock.

The stretch between Mbigiri and Kijungu is uninhabited, and for 40 miles it is covered by scrubby thornbush. A recognised camping place is situated at Kisima cha Mungu where a natural cavernous waterhole in the solid rock holds rain water for part of the year sufficient for human needs but inadequate for cattle.

Kijungu forms a pleasant break in the desolation with its permanent springs of water and a small amount of cultivation, and is succeeded by an alternation of small open grasslands and thorn bush until Kiberashi is reached.



KONDOA IRANGI
4410
Monda
Dalai
Chaimu
Chende
4470
Goima
Gala
Jangalu
Chanika
To Bubu R.
Karema River
Chandama
Mrijo
Boreholes
Kerelawa
Magazini
Foliated Biotite Granite
Njoro
Mbigiri
3850
Kibaya
Mbuyuni
Greenstone
W. 131
Dolerite
W. 124
W. 125
CHENENE HILLS
Meia Meia
Kitunda Hill
Msanga
Hornblende Granite
W. 118
Chilonwa
From TABORA
DODOMA
From Iringa
Kikombo
CENTRAL RAILWAY LINE
Surface Limestone
W. 130
Granulite, 212.
Geiro
Enstatite Basalt, 217.
Pyroxenite, 220.
Mlali
Tubugwe
MPWAPWA
Biotite Muscovite Gneiss, 251.
Gulwe
Kidete
KILO
G.S. 57.
35°30'
5°
5°30'
6°
30'
7°
36°
37°



GEOLOGICAL MAP
TO ACCOMPANY
KONDOA-IRANGI — HANDENI CATTLE ROUTE WATER
SUPPLY REPORT 1928.
REFERENCE
Main Roads surveyed
" " unsurveyed
District Roads
Foot Paths
Administrative Posts
Elevations in Feet.
Miles.
KOROGWE
Zindeni
HANDENI
Crystalline Limestone.
Kwedibomo
Basic Norite. W137
Biotite Gneiss
Kivessa
Greenstone W136
Fresh Water Limestone W134
Kisima cha Mungu
Kijungu
Mutonye
Ngama
Lerok
Lolmunye
Kiberashi
Granulite 189
Mhesa
Barytes
Mlembule
Msanja
Mswaki
Mbwego
Komkoma
Msangasi R.
From Kilosa
Kibuha
Kwadundwa
Kilindi
Lukigura R.
Matembo
Msunga
Vulala
Kyanite 193
Vihingo
Kwakivu
Lembure
Vyadigwa
Kikwazi
Wuyu
Granular-Talc-Actinolite-Olivene-Schist, 202.
Serpentine, 204
Garnet-Quartz-Hypersthene-Rock, 200.
Magnesite, 201.
Tunguli
Talagwe
Biotite-Hornblende Gneiss, 210.
Changwale
KILOSA
To DAR-ES-SALAAM
37°
30'

Kiberashi is the western outpost of the Handeni District, and is inhabited mainly by Wanguu natives with a sprinkling of Wakwavi graziers in the neighbourhood. From this point onwards the country is more closely inhabited and at Kwediboma the first non-native plantation is to be found.

Between Kwediboma and Msanja a " no man's land " seems to form the boundary between the Wanguu and the Wazigua natives who inhabit the remaining part of the road up to Handeni and beyond.

III.—GEOLOGY.

Rock Formations.

The rocks of the area under review may be divided into two classes, the archæan crystalline complex and its derivatives of sand and clay admixtures, and at the opposite end of the time scale, a fossiliferous fresh water limestone of probably recent or pleistocene age.

Crystalline Rocks.

Rocks of this category underlie the whole of the area from west to east and beyond. The prevailing rock is gneiss and admixed biotite and hornblende varieties predominate. One of the striking features revealed in this investigation is the comparative absence of younger rocks intrusive into the ancient crystallines. The dolerites, which are such a feature in other parts of Africa, are represented only by highly altered greenstones of archæan age in which only in rare cases can a doleritic character be recognised. In the few occurrences recorded, microscopic examination shews that all have suffered from thermal metamorphism ; doubtless they were subjected to the same agency which was responsible for the regional metamorphism of the crystalline complex of the Territory.

On account of the importance of the younger dolerites in connection with water supply, this class of rock received special attention.

In this region the only known intrusive rock believed to be younger than the gneissic rocks is a basic norite occurring east of Kwediboma. It was recorded in 1921 by Dr. Teale*, but its relationship with the gneisses has not been determined. At Kwediboma, water supplies being adequate throughout the year, time to investigate this relationship could not be spared from work being performed at places where water shortage was acute.

Crystalline limestones are also of interest and occur astride the road at places near Handeni. They have been burnt for building lime in the past, but at present this useful commodity is imported from the coast, where coral rock is converted into lime by the natives. An analysis of a typical crystalline limestone is shewn on page 6.

The soils derived from the crystalline rocks include sands and clays and an infinite mixture of these two constituents. Sandy soils are to be found on the hillsides and sloping ground, whilst clays occur in the valleys and in the mbugas. The clays forming the valley bottoms are often covered by a thin mantle of sand or sandy soil, and in places boring has revealed a thin band of sand a few feet below the surface of the clay. In the mbugas a clay deposit of over a hundred feet in thickness, of varying sand content, can be expected. An alternation of sand and clay in favourable sites often forms a lodgment for shallow water supplies.

* *Geological Survey of Tanganyika Territory*, 1921. Dr. E. O. Teale.

In places where the underlying bedrock contains a high proportion of ferromagnesian minerals the soil assumes a reddish-brown colour and is more clayey, and this type of country provides a useful road surface in the dry weather.

Recent or Pleistocene Sedimentary Rocks.

Certain parts of Southern Masailand are known to have been at one time covered by fresh water in the form of shallow lakes or marshes. Evidence of this exists in the presence of fine-grained limestone containing fresh-water shells.

Koert* states that Dantz found at a point south-east of Idiro a travertine containing recent land snails determined as a *Cyclostoma Latournensei Bourg. Cycl. zanguebaricum Petit.* Dr. Teale, in his preliminary reconnaissance of the Masai steppe, records a limestone with fresh-water shells at Makami water-holes about 50 miles north of Kibaya, where wells pierce the limestone to a depth of 70 to 80 feet, and yield perennial water. Dantz's occurrence at Idiro lies some 70 miles south of Kibaya, and the writer also records this surface rock at a point some 40 miles east of Kibaya, where the cattle route traverses this formation for a mile or more.

All these occurrences lie in flat-pan-like depressions, which, coupled with the fossil shells, give rise to the belief in previously existing sheets of fresh water.

From a water-supply viewpoint this formation is important since it is known to yield water at Makami, and near Idiro permanent water is to be found, probably associated with this formation.

Two borings that the writer caused to be drilled with the intention of searching for this formation beneath the clays of the Kerelawa depression to the west of Kibaya failed to disclose its existence down to 101 feet when drilling had to be abandoned owing to the limitations of the drilling plant. Since bedrock was not reached in either of these bores the existence of this formation in this depression is still a doubtful quantity.

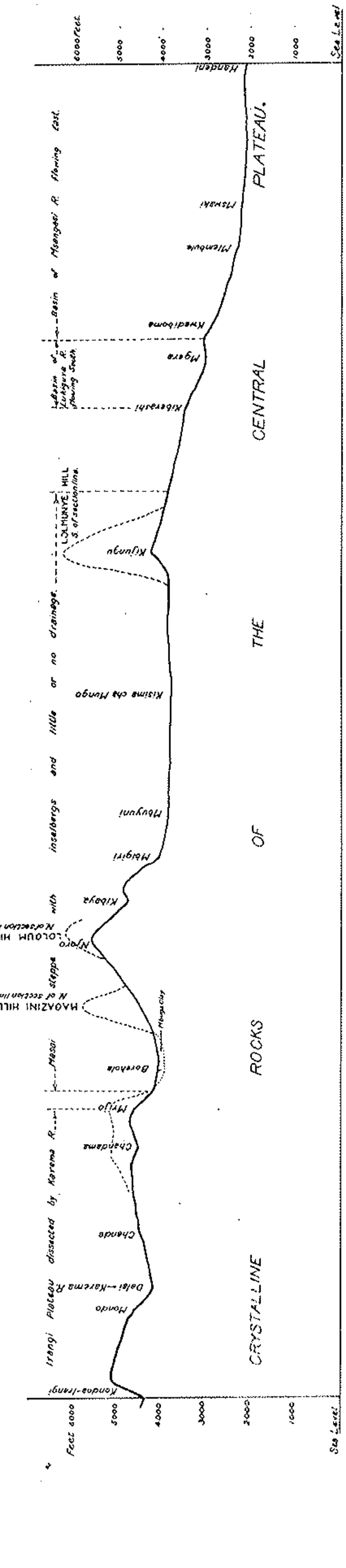
Equally important with the water-bearing potentialities of this formation is the fact that most of the pan-like depressions or mbugas are covered with a heavy grass growth, so that in any scheme for developing water-supplies for the nomadic Masai, where both grass and water must be available together, this formation must be investigated to its fullest extent.

The following analysis of this limestone shews it to possess a high lime content and from a lime-burning aspect to be better material than the crystalline limestone.

Specimen.	Insoluble residue.	Iron oxide and alumina.	Lime CaO	Magnesia MgO	Carbon dioxide.
	%	%	%	%	%
Fossiliferous travertine, WI 34	8·0	6·0	47·6	0·5	37·9
Crystalline Limestone, Ex. 158	15·0	0·5	41·5	5·0	38·0

* Koert, W., Ergebnisse der neuren geologischen Forschung in den deutschostafrikanischen Schutzgebeiten, 1913.

Plate I



PROFILE DIAGRAM KONDOA — IRANGI TO HANDENI.

The lime-burning possibilities of this rock are emphasised, for, in all water conservation schemes, and especially for well linings, a mortar of some form must be used, and the cost of Portland Cement in this somewhat remote region is almost prohibitive.

STRUCTURE.

Faulting.—Like most of the Central Plateau the area under discussion has not escaped the terrestrial forces which disrupted eastern Africa, causing the well-known rift valleys and prominent scarps. The road descends one of these scarps near Mrijo about 36 miles east of Kondoa-Irangi, although the abrupt well-defined scarps so prominent a feature of Kenya scenery are not to be noticed here.

It is recognised that two sets of scarps occur. Mrijo being situated on the older, and consequently more eroded scarp, the descent from plateau to plain is not noticeably abrupt. A little to the north of Mrijo, according to Krenkel,* its oblique direction changes and becomes a meridional one. Owing to the absence of younger geological formations overlying the crystalline complex, definite proof of faulting is often difficult to obtain, and such is the case here, consequently one can only rely on topographical features to bear out this contention. At Mrijo the hills forming the western edge of the Kerelawa depression have a south-west to the north east trend, and then swing round and continue northwards.

Proceeding eastwards across the Kerelawa depression, at Njoro more detailed mapping combined with boring produced evidence of an eroded scarp trending to the north-east, and at right angles to this a set of parallel faults is believed to exist. Boring results give rise to this conclusion and the topography round Njoro itself helps to strengthen this view. (*See* Plate III.)

A few miles eastwards from Njoro the road descends from the Kibaya plateau down to the Masai steppe commencing near Mt. Igiri. The descent here is quite abrupt and suggests a down-faulting to the east. Neither detailed mapping nor boring was carried out here to throw any light on the structure, but it is the writer's opinion that such a fracture exists here, and that the Kibaya plateau is either a horst or else a block of the Irangi plateau left standing at its original elevation.

Krenkel places his third or eastern set of fractures somewhere in the neighbourhood of Kijungu and this feature marks the steep rise from coast lands to the Central Plateau. Little or no mapping was done here away from the road. but the presence of fresh water limestone a little to the west of Kijungu indicates a sunkland which at one time was covered with water. It would seem probable that the fault here has a westerly hade and marks the eastern member of the middle set rather than the beginning of his eastern group.

IV.—PHYSIOGRAPHY.

ALTITUDE AND RELIEF.

The region under consideration lies between altitudes of 6,000 feet and 2,000 feet. At its western end the Irangi plateau has a general elevation of a little above 5,000 feet and Handeni at the eastern end has an altitude of 2,200 feet.

* E. Krankel: Geologie Afrikas.

The highest point recorded is the inselberg mountain of Lerok rising out of the Masai steppe. An almost sheer rise of about 2,000 feet from the steppe to the top gives this mountain an impressive appearance when viewed from the road to the north.

The highest village through which the road passes is Njoro, situated in the gap between the hills of Lolgum and Mwenyibongai, through which the road climbs from the Kerelawa depression to the Kibaya highland.

The Irangi highlands extend eastwards as far as Mrijo and are eroded down by nearly 1,000 feet to 4,200 feet by the Karema River which rises to the north-east of Kondoa-Irangi and flows to the south-west. As Mrijo is approached erosional agencies are manifest in reducing its level, at Chandama, by storm water drainage to the south, and at Mrijo, by drainage to the east into the Kerelawa depression. No prominent peaks are recorded on this portion of the highland, but the Ghost mountain to the north-east of Kondoa-Irangi is said to rise to an altitude of about 7,000 feet.

A glance at the profile diagram (plate I) submitted with this Report, shews the Kerelawa depression in which two unsuccessful boreholes were drilled to approximately 100 feet. This sunkland lies at an altitude of about 4,100 feet and the downthrow caused by earth movement postulated above is in the neighbourhood of 1,000 feet.

Magazini hill occurs as an inselberg rising from this sunken plain, and its highest point is approximately 5,600 feet, or 1,500 feet above the surrounding plain.

The gradient of the road from the Kerelawa depression rises gradually to Mjoro village and then climbs steeply over the pass for a short distance and one looks down upon the relatively small area on which the veterinary station of Kibaya is situated.

This region is eroded by the river Engitikitok and its tributaries, which together have cut through its eastern edge and discharge their waters during the rains into the Masai steppe a little to the south of Mbigiri.

The Masai steppe is traversed by the road between Mbigiri and Kijungu. This steppe lies at an altitude a little below 4,000 feet, and its monotonous scenery is relieved somewhat by hills, often isolated, rising up as inselbergs, the highest of which is Lerok.

The eastern edge of this steppe is defined by a range of hills known as Talamai which stretch away northwards, and on the south of the road a less well defined range extends southwards. It is by no means uncommon in the Territory to find the boundaries of scarp features defined by ranges of hills which rise above the level of both the undisturbed adjoining country, and, naturally, also above the sunken portion.

From Kijungu eastwards the descent to the coastal regions begins, on which is situated the well-defined chain of hills rising up to about 4,000 feet lying between Mgera and Kwediboma, the road passing between a gap dominated by the Kwediboma hill, a cone-shaped mass when viewed from the east and south.

From this point eastwards the country is comparatively featureless, the monotony being somewhat relieved by a small isolated hill to the east of Handeni. It is a shallowly dissected peneplain.

SURFACE DRAINAGE.

The area under review is essentially one with no permanently flowing rivers. The Lukigura River in the Handeni District has a perennial surface flow in its middle and lower reaches, but it is doubtful if this is true of its headwaters, over which the road passes for a few miles between Kiberashi and Kwediboma.

The Kerema River in the Kondoa-Irangi District drains about one-quarter of the region traversed by the road ; about one-half has no well-defined drainage channels, and the remaining quarter is drained collectively by the Lukigura and Msangasi Rivers.

The Karema River is probably the longest of the three, rising as it does near the Ghost Mountain, north-east of Kondoa-Irangi, and ultimately joining the Bubu which discharges into the Bahi depression at the foot of the Kilimatinde scarp on the Central Railway. Where the road crosses it at Dalai its sandy bed is nearly three-quarters of a mile wide, and gives the impression of a very large river. Actually, road-making excavations have shewn that the true bed of this river is comparatively narrow, but that storm waters have brought down and deposited over a wide area such quantities of sand as to create the impression of a wide sand-filled channel. Water is always to be found in this sandy river provided that the original river channel is located.

Proceeding eastwards, Chandama is situated at the headwaters of a stream which flows in a southerly direction, and which may lie within the Kinyasungwi River basin. Near Mrijo the drainage is eastwards into the Kerelawa depression.

The portion of the Kibaya upland crossed by the road is situated within the basin of the Engitokitok River which rises a little to the west of Kibaya, is fed by tributaries from the north, and discharges its waters (during the wet season) into the Masai steppe near Mbigiri, where it loses its channel under sheets of sand. As a source of water in this arid region this river is invaluable. Within the Kibaya basin perennial springs are to be found at the sides of the dry river bed, and small attempts at conservation by a masonry dam and excavations have enabled a much larger number of cattle to be watered here in the dry season.

In the Masai steppe it can be said that there is no defined drainage. For a short time after the rains large pools of water dotted over its surface indicate small local sumps, but well-defined channels are conspicuous by their absence. The run-off from this area is nil and the annual rainfall is disposed of by absorption and evaporation, in, probably, equal quantities. Like the well-defined channels mentioned above, rainfall records in this wilderness are also conspicuous by their absence.

Between Kijungu and Kiberashi there exist clay covered depressions indicating poor drainage, and the general maps of the Territory shew a drainage to the south.

Immediately to the west of Kiberashi a low watershed exists which cuts off drainage to the east and it is possible that the general maps are correct in this respect.

The head waters of the Lukiguru provide a southerly drainage to the Indian Ocean in the area between Kiberashi and Kwediboma, and from Kwediboma eastwards the road runs parallel to the thalweg of the Msangasi River, which flows only during the rains, and then sometimes with devastating violence.

V.—PRECIPITATION.

The following rainfall records are compiled from figures contained in " Handbook of German East Africa, 1916," which supplies pre-war information, and, for the post-war figures, the writer is indebted to the District Officers of Kondoa-Irangi and Handeni respectively, and to the Stock Inspector at Kibaya, Mr. A. G. Gowan, who made a praiseworthy effort to gauge the rainfall at Kibaya from 1924 to 1928 by directly measuring with a foot rule the rain water caught in a V.P.K. developing tank.

A glance at these statistics shews a great disparity between the annual mean rainfalls at each end of the road, both as regards total precipitation and its distribution.

Handeni records shew some rain to fall throughout the year, and a " dry " period of about four months' duration, with a mean total of 28·3 inches per annum.

Kondoa-Irangi figures shew the dry season to last for about six months with a mean precipitation of about 21 inches.

From observations of vegetation it is thought that in the neighbourhood of Mgera, where hills rise to 4,000 feet, the total rainfall is probably higher than at Handeni, and also, that " oases " of 30 inch rainfall probably exist in the Masai steppe on the eastern slopes of the higher hills such as Lerok, Lolmunye and the Serian Hills to the north of Kibaya, whilst the actual precipitation on the steppe itself probably does not reach that of Ugogo, say 18 inches.

A notable example of the sporadic distribution of rainfall in the neighbourhood of rising ground has been arrived at by the researches of the members of the Tsetse Research Branch of the Game Preservation Department in a region north of Kondoa-Irangi. They find that a difference of 3 inches is recorded in as many miles as one proceeds eastwards from a high scarp into the plain.

The rain-bearing winds of the Territory blow from the Indian Ocean and on encountering mountainous slopes like the Uluguru and the Usagara, and mountain ranges like the Unguu, which define the eastern edge of the Central Plateau, they are forced upwards into colder altitudes where rain is formed and this rain, falling with a velocity compounded of the westward velocity of the wind and the force of gravity, reaches the earth much further inland and causes an arid strip of country to extend from Arusha in the north, through Dodoma, and even on to the Northern Rhodesian boundary. The increase in precipitation on the eastern slopes of scarps and mountain ranges is explained by the eddy currents formed when the rain-bearing winds have their forward velocities changed on meeting these obstructions.

RAINFALL.

HANDENI (KWAMDOE). (Altitude 2,210 feet above sea level).

PRIOR TO 1914.

No. of years' observations prior to 1914	4·6	1927/28	1928/29	No. of years' observations prior to 1914	4·6	1927/28	1928/29
	Inches	Inches	Inches		Inches	Inches	Inches
				Forward ...	7·00	8·67	10·45
June... ...	0·59	—	4·65	December ...	3·74	6·07	2·25
July... ...	0·94	—	0·00	January ...	3·19	0·24	2·52
August ...	0·67	0·30	0·42	February ...	1·30	1·13	0·00
September ...	1·30	0·63	0·47	March ...	4·53	3·96	2·38
October ...	·94	5·65	1·29	April ...	7·01	6·31	4·25
November ...	2·56	2·09	3·62	May... ...	3·74	5·10	1·06
Forward...	7·00	8·67	10·45	Year—Total	30·51	31·48	22·91

Mean annual precipitation = 28·30 inches.

KONDOA-IRANGI. (Altitude 4,510 feet above sea level).

No. of years' observations prior to 1914	8·5	—	—	—	—
	Inches	Inches	Inches	Inches	Inches
June	0·04	0·00	0·00	0·00	0·08
July	0·00	0·00	0·00	0·00	0·00
August...	0·00	0·00	0·00	0·00	0·00
September	0·00	0·00	0·61	0·00	0·00
October	0·08	1·76	0·45	0·12	0·09
November	0·67	0·71	2·90	0·00	0·06
December	5·43	3·02	5·82	3·18	3·73
January	3·74	5·27	6·62	0·16	5·21
February	3·98	1·66	1·78	2·51	0·75
March	4·09	2·99	7·28	4·54	6·19
April	3·42	4·32	1·32	2·40	1·98
May	0·55	0·25	0·57	1·34	0·00
TOTAL	22·00	19·98	27·35	14·25	18·09

Mean annual precipitation = 20·33 inches.

KIBAYA. (Altitude 4,760 feet above sea level).

	1924/25	1925/26	1926/27	1927/28
	Inches	Inches	Inches	Inches
June	0·00	0·00	0·00	0·00
July	0·00	0·00	0·00	0·00
August	0·00	0·00	0·00	0·00
September	0·00	0·00	0·75	0·00
October	0·00	1·75	0·00	0·25
November...	0·25	3·00	0·25	0·50
December...	1·25	4·25	1·25	3·50
January	1·75	4·00	5·00	2·50
February	3·50	5·25	1·00	5·00
March	2·75	1·00	9·75	2·50
April	1·25	3·00	0·25	1·25
May	0·25	0·25	0·00	0·00
	11·00	22·50	24·25	15·50

Mean Annual ... ... 18·31 inches.

VI.—GROUND WATER.

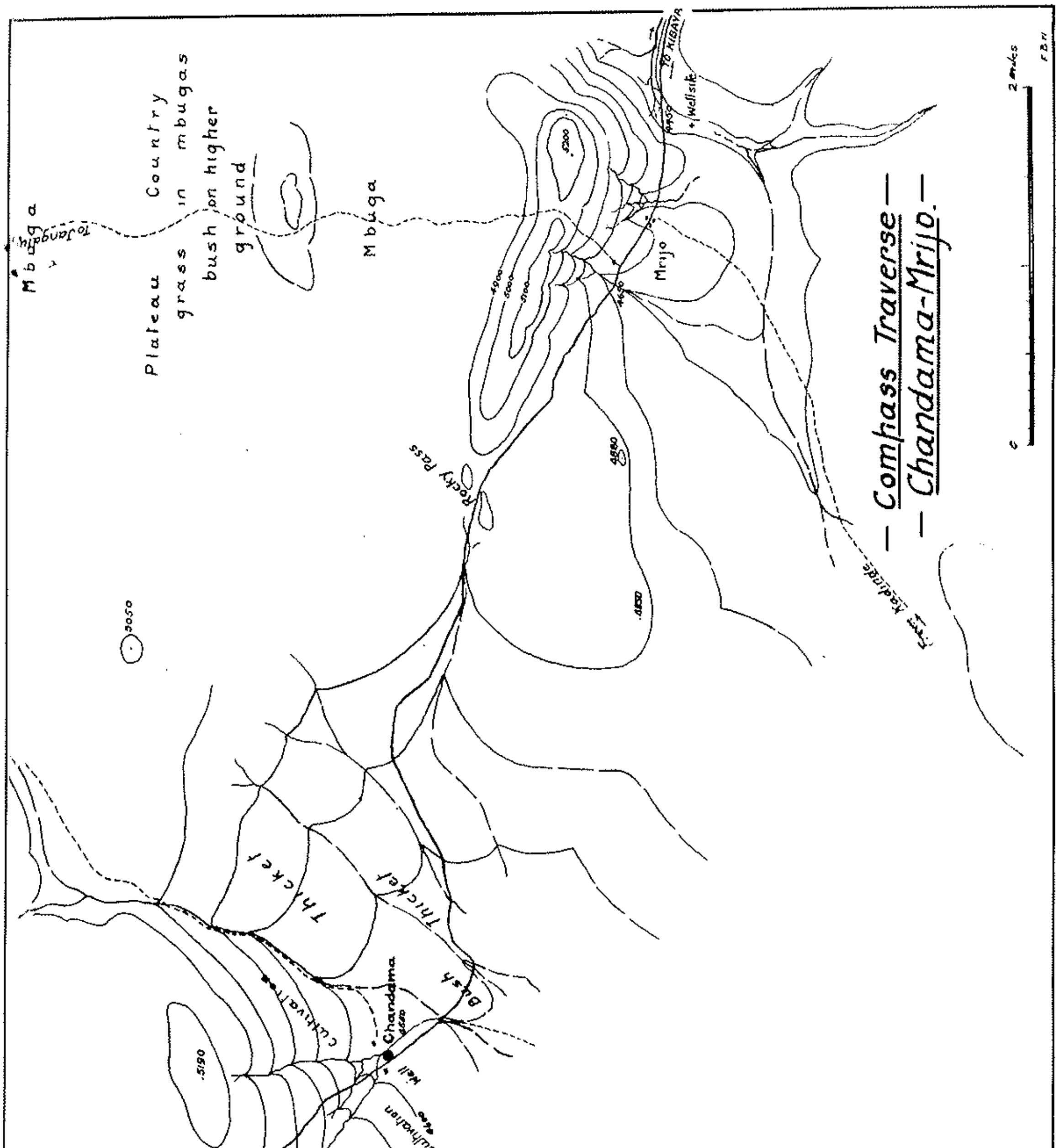
Ground water is defined as that portion of the rainfall which, sinking into the ground, saturates the voids of the rocks. Some rocks contain more voids than others and consequently are capable of yielding more water when tapped by wells or boreholes. In a bedrock such as the crystalline complex of the area under review, it is stored mainly in joints caused by original cooling or in shatter zones such as might be caused by stresses set up by earth movements like the rift dislocations.

Ground water, like surface water, is subject to the force of gravity and moves from higher levels to lower, but naturally much more slowly than surface water. The imaginary surface below which rocks of the earth's crust are saturated with water is known as the water table, or ground water level. This is not a level surface but is conformable with the profile of the countryside. It flows from under hills into the valleys thereby raising the water table under the valleys, and in this way often causes springs to appear in valleys some time after the rains have ceased. In countries having perennially flowing rivers and permanent lakes, the water table is actually above the level of the river or lake and so water flows into them.

At Kondoa-Irangi, the water table appears to be close to the surface in many places. The river Kondoa is a permanent stream ; at the junction of the Dodoma-Handeni roads a small permanent lake is seen, and on the eastern slopes, down to Mondo, many ponds were to be seen even as late in the year as October. This portion of the Irangi highlands is covered with a very sandy soil overlying the crystalline-complex bedrock, and it is to this sandy cover that the comparatively steady yield of ground water is due. Unhappily, this sandy soil is annually being swept away by erosion assisted by thoughtless over-cultivation and over-grazing, and is being carried down to the plains where the rainfall is so much lower, and a regional water shortage must inevitably ensue in the neighbourhood of Kondoa-Irangi.

As the valley of the Karema River is approached sandy soil gives place to a hard clay sub-soil with a thin cover of sand. Doubtless this clay deposit is of sufficient thickness and sufficiently impervious to " blanket " the emergence of the water table. On the western bank waterholes are used throughout the year, but the inhabitants of the east bank at Dalai depend on obtaining supplies from holes scratched in the sand of the river itself. Ponds excavated in the clay on the eastern bank dry up before the end of the dry season. If the thickness of this clay " blanket " is not too great to be pierced by wells ground water should be found under a static head which might even produce a flowing well, provided the bedrock is sufficiently decomposed to increase its normally poor porosity, and thus act as a medium for the circulation of ground water.

At Chende the inhabitants depend on a submerged spring in a small dry river bed, which yields barely enough for their domestic needs. A well was being sunk in a neighbouring and larger stream valley near by and at the time of the writer's visit it was 12 feet deep through sandy clay and water level was ascertained to be at about 15 feet. Bedrock had not been reached, so it is possible that this well when completed and carried down to bedrock will yield a permanent supply since the ground water appears to be under


Compass Traverse
Chandama-Mrijo
Plateau Country
grass in mbugas
bush on higher ground
Mbuga
Mbuga
Rocky Pass
Mrijo
Thicket
Thicket
Bush
Cultivation
Chandama
Well
From KONDOA
To KIBAYA
Wellsite
2 miles
0

a head sufficiently great to saturate the sandy clay. It is improbable that the water table at Chende is directly influenced by the high ground between the Karema River and Kondoa-Irangi, but the eastern bank of the Karema River basin is sufficiently covered with sandy soil to cause a high absorption of its somewhat smaller rainfall.

The next important point on the road is Chandama. Here the cattle drovers water their cattle, having come from their previous watering place, Dalai, 17 miles away.

Water is found here in comparatively large quantities about 4 feet below ground level, and is a perennial source of water on which the natives living even as far away as Mrijo are said to depend in exceptionally dry seasons.

The waterholes lie in a shallow clay-filled valley which is fed by several more deeply-cut channels to the north-west (*see* Plate II). These tributaries conduct the rainfall from the slopes of the hills and concentrate it in the shallow valley at the waterholes. During the rains the surface flow is intermittent and in the nature of a flood which quickly drains away down the valley, where little, if any, penetrates through the clay covering the bed of the valley.

Since the surface flow can influence the supply but little, how can the perennial source of water be accounted for ? Undoubtedly the general water table under the higher ground to the north-east and to the north (where a large upland region extends with practically no drainage for ten miles) is responsible for the steady flow. But if this is the case, why are there not more springs in the same valley lower down ? It is possible that the clay cover in the valley effectively blankets such springs if they exist.

Another influence cannot be disregarded ; that is, faulting. Chandama is well within a possible disturbed zone caused by the faulting further east. In general, the strike of the granitic-gneisses forming the country rock in this region is east to west and the dip is steep to the south. In the neighbourhood of the waterholes, two sets of strikes are recorded, one trending south-west to north-east with a dip to the south-east, and one trending nearly east and west. The topography of the region also reflects these structures. The hills to the north-west of Chandama trend to the north-east, whilst those east at Mrijo combine both tendencies. It is therefore not impossible that a fault plane exists near the waterholes striking to the north-east and thereby tapping the higher water table of the plateau country to the north and north-east.

Under the writer's direction a shallow well with a lateral feeder was constructed here at the end of the dry season of 1928. A cattle trough was installed and it is hoped that this means of watering cattle will be adopted by the local inhabitants instead of the wasteful method of allowing the cattle to walk into shallow ponds scooped down to water level.

The water supplies at Mrijo (*see* Plate II) about six miles along the road to the east bear a similar relationship to the Chandama supply just described, only the yield is sufficient only for the present domestic needs. The main supply is from waterholes dug in the small valley immediately east of the main collection of native houses which constitute the village. From the paucity of yield the source is probably a spring or springs fed from the higher ground to the north, and not supplemented by a water-bearing fault as was postulated at Chandama.

Another less reliable source of water of similar character is to be found in a small valley about half-a-mile westwards. Here, to the south of the road is a shallow waterhole which fails as the dry season advances. It is situated about 100 feet higher than the main supply and is evidently on a water table which falls more rapidly than the supply at the lower elevation.

The writer investigated the potentialities of the clay-filled valley crossed by the road about half-a-mile east of Mrijo.

This valley lies at a still lower elevation and a series of boreholes up to the valley shewed the weathered bedrock to yield water under a static head of about 10 feet, and subsequent observations shewed that the water table in this valley remained stationary at about 13 feet below the valley bottom up to the beginning of October. During the remainder of October and the whole of November observations were not recorded owing to the water being used by the inhabitants and by the writer's well-sinking gang being occupied in constructing a well at this point.

This well was not completed with masonry or concrete owing to the approach of the rains, and to the more pressing need for the construction of a good well at Chandama, and to the fact that the cattle drovers asked that a well be made at Dalai in preference to one at Mrijo. For the needs of the local inhabitants and not especially for cattle using the trade route, this well should be completed.

Boring results in this valley shew the water table in it to be " perched," and the valley itself to be a hanging valley. Whilst water is found in boreholes from 200 yards south of the road, a borehole close to the road reached a dry bedrock at 13 feet. To the north of the road, where the valley swings round to the east, bedrock is exposed in the erosional channel and is dry. The general strike of the bedrock is west to east and the dip to the south, and it is probable that a harder layer of the bedrock extends across the valley below the surface and acts as a barrier behind which the ground water lodges.

In the Kerelawa depression, boring down to 101 feet failed to reach the water table. These boreholes are located about 5 miles east from Mrijo and throughout their depth passed through only the blanketing clay which is so characteristic of regions of poor drainage in this country, and no bedrock was reached. When boring was commenced it was hoped that the recent freshwater limestone might be encountered at about 70 feet, and rock of this sort should be more water bearing than the crystalline gneisses. Since no bedrock was reached and no water found, both the geology and the hydrology of this wide plain are still a matter for conjecture.

Njoro (*see* Plate III and frontispiece) situated on the eastern edge of the Kerelawa plain, is the gateway to the Kibaya Plateau, and is a recognised stopping place for trade stock, and a well known watering place for some of the Masai herds.

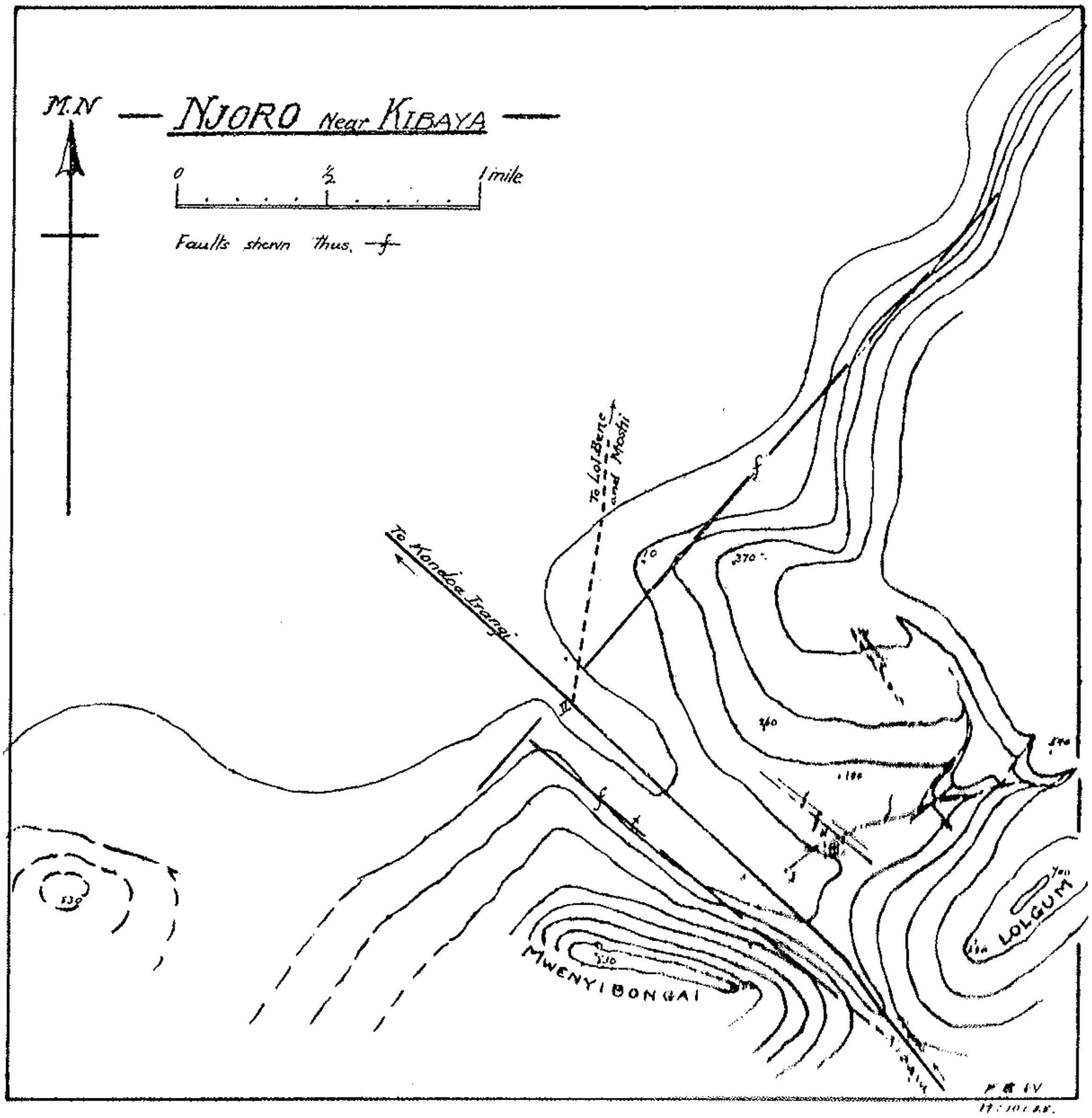
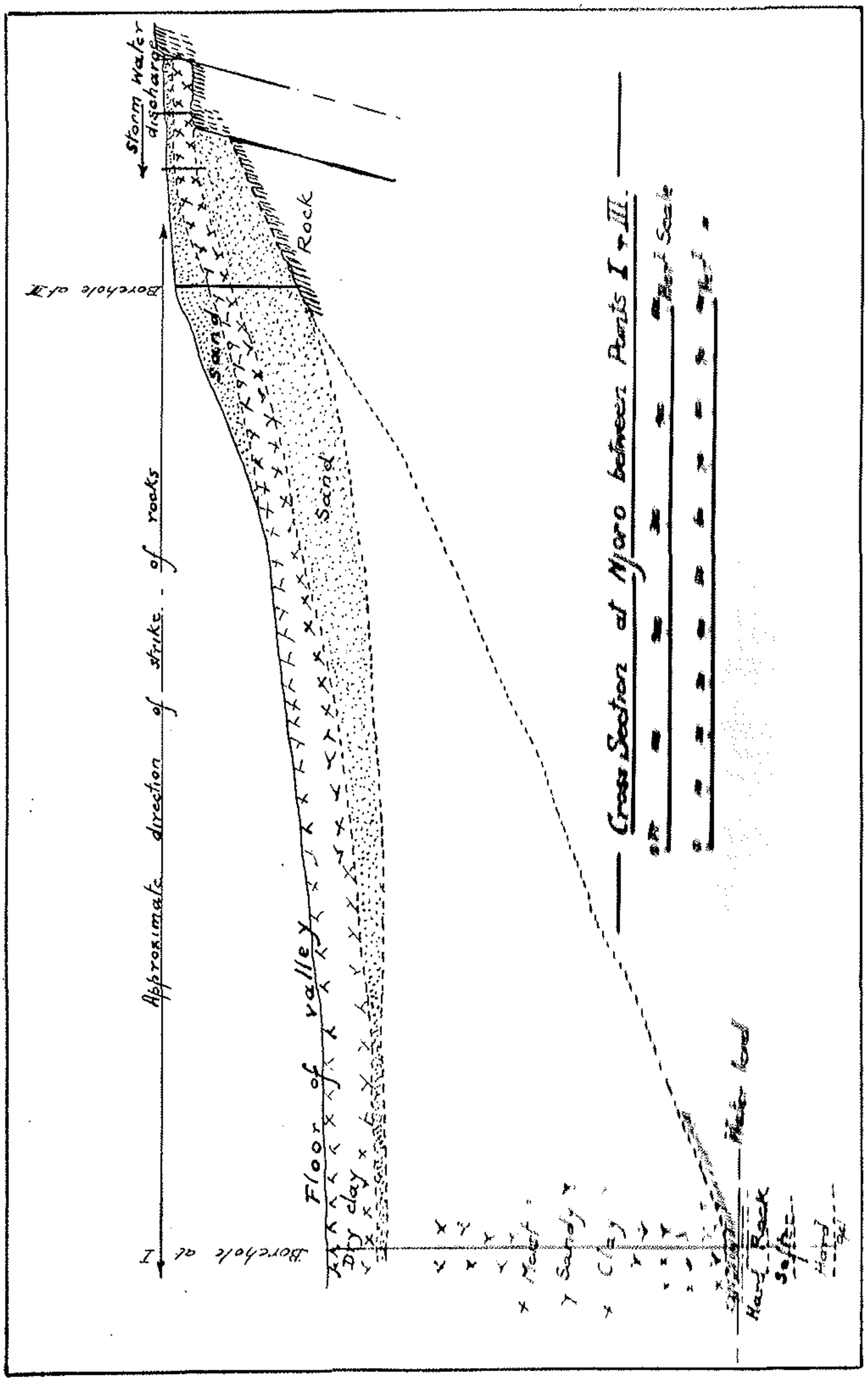

M.N
NJORO Near KIBAYA
0
½
1 mile
Faults shewn thus.
To Lol Bene and Moshi
To Kondoa Irangi
370
MWENYI BONGAI
LOLGUM

PLATE III



Cross Section at Njoro between Points I & II
Storm water discharge
Rock
Borehole at II
Sand
Sand
Approximate direction of strike of rocks
Floor of valley
Dry clay
Borehole at I
Marl
Sandy
Clay
Hard Rock
Soft
Hard

For a part of the year after the rains, cattle are watered in the stream which drains an area to the north of Lolgum. This surface flow dries up as the season advances and a diminishing number of cattle is watered from waterholes dug in its bed. On the 10th July, 1928, it was flowing steadily, but by the end of August the surface flow had ceased and the sub-surface saturation was being drawn upon.

As to the ground water of Njoro, boring results shew that it is situated in a small area dislocated by faulting. The narrow valley itself was caused by the slipping down between fault planes of a narrow block of the range of hills forming the western edge of the Kibaya Plateau, and the amount of dislocation seems to have been greater on the south-western side. The north-eastern slope of Mwenyibongai Hill presents a ragged view of strata dipping to the south-east, whereas the other side of the Njoro valley shews as the eroded edge of a tilted shelf stretching to the north-east. This shelf meets the Njoro valley at the foot of Lolgum where the storm waters running from it have commenced cutting back into it. These periodical discharges have brought down a sandy silt which is beginning to fill the upper part of the valley. Bedrock is exposed in the upper reaches of the drainage stream, but disappears abruptly on entering the valley, and at the centre of the valley, about 370 yards away, it is 74 feet below the present bed of the valley.

Water was struck in the deepest borehole at 89 feet, and it rose to 76½ feet in the bore. The bedrock pierced was found to alternate in hardness, and from outcrop observations it is found that the harder strata are formed of more quartzose gneiss, and the softer are more felspathic. The softer rock weathers the more easily and consequently should be a better medium for the circulation of the ground water.

The yield from this borehole was disappointingly small, being only from 12 to 13 gallons per hour, and it is thought that deeper boring would increase its yield, and might even tap a fault plane which would undoubtedly augment the yield.

As a supply of water for trade stock this borehole was not developed, as funds did not admit of the expense likely to be incurred in casing the hole down to bedrock, in providing a pump and some means of operating the pump, either by windmill or by hand, and (since the yield is small) in providing storage tanks.

A well was dug and a trough provided for trade cattle about half-a-mile north of the road near where the Masai usually dig their waterholes as the season advances. This new well is on the left bank of the stream and does not interfere with the Masai waterholes, since an old buried channel was struck and a new supply tapped.

Although this well was dug primarily for the trade cattle being driven to market through Masai country, it was being used most enthusiastically by the local Masai, and it is unlikely that it will ever be set aside by the Masai purely for the use for which it was constructed.

When the needs of the Masai are considered, all the supplies at Njoro should be developed. It is about 6 miles away from the permanent supplies at Kibaya, and therefore near the edge of the grazing radius from Kibaya. The plains to the west of Njoro provide grazing which would be available if water were more plentiful at Njoro.

Kibaya.—The Kibaya uplands are comparatively well watered, and for a long period during the year the water table is sufficiently high to feed some of its streams and cause them to flow, but at the critical period, before the new rains commence, only one or two springs in the more deeply cut channel of the Engitokitok River continue to flow. This flow has been supplemented by digging waterholes at favourable places principally on the north bank.

This is the only place along the road where any attempt has been made to conserve the surface water, and the dam built by a former Administrative Officer serves a very useful purpose.

The Veterinary Department maintains a cattle dip here, and all trade cattle passing along the road are obliged to be dipped here to minimise the spread of disease. This rule necessitates the provision of watering facilities for trade cattle before being dipped, since it was found that thirsty cattle sometimes drank the dip whilst passing through the arsenical solution, and some deaths ensued.

The writer installed a watering trough here supplied with water from one of the above-mentioned waterholes by means of a semi-rotary hand-pump and piping. This mechanical pump was installed as an experiment and its use, by the Masai principally, proved that pumps of this sort are not a success, being too easily put out of action by the primitive native who also fails to realize the necessity of priming the pump with water when it fails to draw on starting up.

The waterholes at Kibaya should be adequately supported by masonry, since they are permanent supplies, but cave in each year during the rains.

Mbigiri.—Like Njoro, this place is important from a grazing view-point and also as a collecting centre for trade stock which has passed through the dip at Kibaya. It is important that they should be watered here before setting out to cross the sometimes waterless stretch to Kijungu. At a point about 7 miles from Kibaya where the now sandy bed of the Engitokitok River approaches the road a shallow waterhole is to be found on the north side of the road. This water does not last right through the season, and its yield is barely sufficient for the needs of the few settled natives who cultivate a few fields near the higher ground.

The supply on which the natives depend when the above waterhole dries up is the water to be found under the sand of the river. An effort was made to investigate this supply but owing to the depth of sand and inadequate appliances it was abandoned and a well was dug on the north bank in the bed of a tributary where bedrock was reached at 15 feet and was pierced for 6 feet, when the inflow of water was considered adequate to justify constructional work and trough building. When this well was visited on the 5th of September it contained 12 feet of water, but a month later it was practically dry. The local natives had been drawing heavily upon it, but at the same time the water table must have fallen unusually quickly. It is evident that any well to be successful here and to yield water in sufficient quantity for cattle purposes must be dug deeper than the lowest point to which the water table sinks and it must be of fairly large diameter to ensure a good inflow from the decayed gneiss bedrock, which is not as a rule rock of high porosity.

Kisima cha Mungu.—About mid-way between Mbigiri and Kijungu and in the middle of the 40-mile stretch of wilderness are found three wells penetrating the gneissic bedrock which is exposed in the neighbourhood.

The smallest of these wells is at Kisima Kidogo, about 2 miles west of the other two. This can hardly be described as a well, being merely an irregular cleft in the bedrock, probably caused by solution. This contains a small amount of water for a very short period.

The other two wells are situated 18 feet apart in a natural depression in the bedrock. This depression is partly filled with clay, and during the rainy season it becomes a rain-pond and affords water for trade stock. Rain water also fills the two wells, and the lower lying rain-pond acts as a sump in which silt is deposited and thus the deeper wells escape being filled up with sand and soil from the surface.

Both these wells were cleaned out by the writer's party and it was found that one was 44½ feet deep and the other was 26 feet deep. The deeper of the two was dug by the Germans prior to the war, and is roughly 7 feet in diameter. The other is a natural solution hole which has been made bigger by probably both the natives and by the Germans. It is cavernous at the top and the opening into it is an irregularly shaped aperture about 2 feet by 4 feet. Below the cavernous upper part a well was commenced and goes down 13 feet, being about 7 feet in diameter at the commencement and tapers to 5½ feet at the bottom. A borehole of undetermined depth was found piercing the bottom.

These wells are merely underground storage tanks and are uninfluenced by ground water, and, although so close together no interference seems to take place. Before the work of cleaning began, the water level in the shallower well was 8 feet from the surface, and in the deeper it was 34 feet from the surface.

Since these wells were of a limited capacity no further work was done on them for cattle watering purposes. They serve a useful purpose, however, in that they are a source of water to foot travellers crossing this wilderness, and Kisima cha Mungu is a well-recognised camping ground.

Kijungu.—A permanent supply of water exists here a little to the north of the road in the foothills of the Talamai Mountains. Two springs issue from a hillside in a narrow valley trending southwards, and their united flow is completely absorbed by the soil after running about 200 yards. In the past the natives, both Masai cattle traders and the few cultivators settled there, watered their stock from a roughly-made dam built at the end of the stream, but the writer on gauging the flow found it advisable to tap the springs themselves in order to prevent the undue wastage by absorption. On the 7th September, 1928, the flow from spring "A" was 1 gallon per minute, the flow from "B" was about ½ gallon per minute. At about 500 feet lower down the flow was 0·9 gallons per minute, showing a loss of 0·6 gallons per minute, or 40 per cent. of the small total yield. Obviously, with such a small but permanent flow, storage must be provided, and its flow through furrows must be reduced to a minimum.

The writer caused the highest spring ("A") to be dammed where it issued from the hillside, and from this a pipe conducts the water to two concrete tanks which store up 310 gallons. From the tanks water can be run through a stop-cock into a trough which holds another 100 gallons. This stored supply should be sufficient to slake the thirst of about 100 cattle on arrival from across the dry steppe, and the following morning, before setting out on the next stage of the journey, a similar drink can be obtained.

In theory this should be a great boon to the trade stock; actually, on completion of the work the local Masai graziers forsook their accustomed waterholes situated to the north-east along the eastern slopes of the Talamai Range, and concentrated on this new one where their cattle could be watered with the minimum of trouble to themselves. Considering that the Masai people have contributed nothing towards the cost of this work, and that it was intended purely for trade stock, steps should be taken to regulate the use of government watering places, or alternatively, the Masai should be provided with their own watering places at their own expense. At Kijungu only one spring was harnessed; the other one is still running to waste, and it is understood that many similar springs are to be found along the eastern slopes of the Talamai. In this area alone much could be done cheaply to provide more abundant water for the Masai if that were desired.

The valley in which the springs occur has been carved out of a hill composed of a quartz rock in which the quartz occurs coarsely granular. Small specks of mica are to be seen in the quartz. This rock strikes at 120 degrees and dips to the south at an angle of 50 degrees from the horizontal.

Kiberashi.—At 18 miles from Kijungu the headwaters of the Lukigura River commence in a spring quite close to the road on its north side. Here the cattle of the local Wakwavi are watered in the dry season, and about a mile lower down a place has been set aside for trade stock. This is a very muddy pool from which the local cattle are not entirely excluded. When time and money are available a little conservation and fencing would improve this watering place.

From here onwards the country is comparatively well watered and grassed, but between Kwediboma and Handeni in the basin of the Msangasi River, the poorly-made waterholes do not provide sufficient water for trade stock, so they are hurried on to Handeni where provision has been made for them. It was desirable to provide water, if possible, for cattle near Mswaki, so investigations were conducted on the hydrology of Mswaki.

Mswaki is situated in the basin of the Msangasi River, which here is simply a shallow clay-filled valley with no well-defined channel and no surface flow except in the rains. Several tributary valleys enter near Mswaki and in one of them which crosses the road just east of the village a trial borehole yielded encouraging results and it was afterwards converted into a well. It was found that a shallower supply of brackish water exists below the bed of the main valley, whilst the tributary stream yields only fresh water.

In 1913 the Germans dug a well and constructed a trough a little to the east on the slope of the main valley, and on entering the bedrock at 21 feet it is said that a plentiful supply of fresh water was struck, sufficient to justify building a long trough and to instal a semi-rotary hand pump and piping. This old well has not been of use for cattle since the war, and in September it was dry. The writer had it cleaned out and deepened to 23 feet when water began to seep in, shewing that the water table was in mid-September from 23 to 24 feet below ground level.

A little to the north of the village, higher up the tributary valley, a village waterhole is situated. This is simply a large hole dug in the clay, the dry banks of which are nearly vertical and seem to stand up well, but near water level the wetted clay subsides into the water and renders the amount of water available very small. Water level in this waterhole was at 24½ feet from ground level. On the completion of the new well for trade cattle the writer has reason to believe that the inhabitants abandoned their own waterhole in favour of the new one, from which water could be obtained more quickly and more easily. It was gratifying to know that the native Administration of the Handeni District, no doubt encouraged by the success of the new well at Mswaki, and realising the benefit that more wells will confer on the native inhabitants, has set aside from Native Treasury funds a sum of money with which to undertake a well-sinking campaign during 1929.

It is possible that the yield from the new well at Mswaki fell short during the critical period for the district due to the heavy demands made on it, but at the time of its completion, whilst still under the control of members of the survey, its yield was ample for the purposes for which it was constructed, namely, for watering the trade stock passing through to the market at Korogwe.

Handeni.—The next watering point for trade stock is at Handeni itself. Here, in 1927, at the recommendation of the Director of Geological Survey, a cut-off wall was constructed across a small valley over which the main road crosses by embankment and bridge, within half-a-mile of the Administrative Office. The dam contained some surface water at the end of September, and it was being drawn upon by the inhabitants of Handeni for domestic purposes. The source of the supply to the cattle trough is situated beneath the present muddy bottom of the dam. It is tapped by a well 18 feet deep, the sides of which are supported by corrugated iron rings, and the water enters it under a small head which is noticed when the water level is lowered by vigorous pumping. At the time of the writer's visit an old worn-out semi-rotary pump installed as a makeshift was not functioning, and a new pump of similar design was waiting to be installed. The writer caused the new pump to be fitted and saw the trough once more in operation. From Handeni the trade stock proceeds to Korogwe via Zindeni where a plentiful supply of water is obtained from a perennial bubbling spring of deep-seated origin.

VII.—CONSTRUCTIONAL WORK.

The executive side of the Water-supply Section of the Geological Survey consists of two units, one under the Boring Foreman and the other under the Well Foreman. The function of the former is more or less exploratory, whilst the Well Foreman's party digs wells, constructs troughs, tanks, etc., and instals pumps, or other types of water-raising appliances. Each European foreman employs a small gang of natives, some of whom soon become specialists in some small part of the work.

PLANT.

The boring plant used was an Isler hand-powered percussion drill capable of drilling down to 100 feet. It is eminently suitable for exploratory work in clays and soft sandstones, but for drilling in the harder igneous rock its drilling speed is very slow, and the wear on the chisel edges is great. For drilling into the harder rocks a rotary drill gives a greater drilling speed but requires much more water, and the provision of water when drilling in waterless country limits the scope of a rotary. A combination of the two types should give more satisfaction, and provision has been made this year for this combination.

The plant used by the Well Foreman is somewhat more complex, and its use depends on the type of work to be done. One of the most useful pieces of plant was a Winget hand-powered portable concrete mixer, and for well-linings a meter diameter culvert pipe mould was found to give excellent results both for lining wells and for making storage tanks and troughs.

Half-a-dozen troughs made of galvanised sheet iron and angle iron were constructed in the dockyards workshops in Dar-es-Salaam to a design submitted by the writer. These proved to be very useful and easy to erect, but are liable to be damaged when transported by motor over long distances. They are also subject to the corrosive action of the water and weather, and have a limited life. At Mswaki a concrete type of trough was installed as an experiment, and if it proves satisfactory it will be used by the Department as a standard type, since its cost is approximately one-third that of the iron type, and its life should be infinitely greater.

Three " roadless " wheelbarrows were employed as part of the equipment and were found to be far superior to the old type when shifting earth on dumps and soft banks.

Two Albion 2-ton lorries burning paraffin were at the disposal of the survey for part of the time, and stood up to the rough conditions very well. They were indispensable in rationing the parties in the inhospitable Masai steppe, where no foodstuffs can be obtained. Native labour was obtained as far as possible at the well-sites, but in the Masai country Warangi labourers were brought from around Mondo.

Types of Water-supplies.

Dalai.—Although no constructional work was performed at this place, exploratory work revealed conditions which are worthy of record. A line of pits running from east to west towards the river shews the bed of the valley to be covered with a hard black clay overlain by a whitish clay bed 3½—2½ feet thick, which is in turn covered by a sandy mantle up to 18 inches deep. No water was found in the clay down to 9 feet deep. At about 30 yards from the present river margin the clay is hollowed out by former river scour and at 4 feet 6 inches deep at the end of the dry season a grey sand occurs resting on the black clay, and in this sand water was obtained at the rate of from 80 to 100 gallons per hour. It is hoped to construct a proper well here and to provide a trough for trade cattle.

Chandama.—This is somewhat similar to the formation described at Dalai in that water occurs a few feet below the surface in a sandy-clay bed. The underground flow is down a shallow clay-filled valley and so an infiltration galley filled with broken stone, 50 feet long, was constructed athwart the flow to supplement the flow into the well. The sides of the well were supported by concrete rings 1 metre in diameter for 12½ feet, and additional storage was provided at the bottom by a culvert 10 feet long. On completion at the end of the dry season the well was left undisturbed for 24 hours and pumping with a diaphragm pump shewed it capable of supplying more than enough water for the demands likely to be made on it.

Mrijo.—No construction work was done here, and the results of exploratory work have been described in the previous chapter. Mention is made of it here since it differs from the above two types in that the bulk of the water emanates from the decayed bedrock. In consequence, its yield as a well will be smaller and slower, and any constructional work done here should be in the nature of a large well of, say, 8 feet finished diameter, to increase the inflow and storage capacity.

Njoro.—Exploratory boring shewed that the most feasible scheme to follow here was to dig a well in the bank of the stream near the dry-season waterhole of the Masai and to tap the ground water in the bedrock at this point. In the course of digging, an old buried stream channel in the bedrock was penetrated and an old and evidently pre-Masai digging-stick was unearthed. Unfortunately it was burnt for firewood before its importance was realised.

The well was lined by means of concrete rings and was completed with trough and piping. In quantity its yield should be sufficient to slake the thirst of cattle arriving from across the plain before they proceed on to the water at Kibaya. From the way in which it was being utilised by the Masai, even before it was completed, the chances of any alien stock-drovers watering their cattle here are remote.

Kibaya.—One of the existing waterholes excavated at the instance of the Stock Inspector was equipped with a semi-rotary pump, piping and a trough.

Mbigiri.—Exploratory work in the river bed was unsuccessful, but well-sinking on the left bank reached water-table in decayed bedrock. No constructional work was done here but information was gained for future developments.

Kisima cha Mungo.—Exploratory work proved that the wells were merely rain-water storages filled annually by run-off from the surface, and that the water-table here was deeper than 45 feet.

Kijungu.—One small spring was developed by having a little concrete basin constructed at its point of issue from the hillside, and from here the spring-water was piped through 2-inch galvanised pipes to two concrete storage tanks. These storage tanks were made by cementing two concrete rings side by side upon a concrete plinth, connected to each other at the bottom and provided with a stop-cock whereby the flow of stored water could be regulated into a trough installed close by. A cattle track was cut through the bush for about a quarter of a mile to enable the stock to reach the new watering point.

Mswaki.—Beneath the clay covering the shallow valley a water-bearing sand was encountered at about 21 feet down in an exploratory bore-hole. A well was dug here and since it was not possible to reach bedrock owing to the strong inflow of water, the sides had to be supported in the following manner. A set of four concrete blocks was made which when placed together formed a circular slab with a hollow square inside it, These blocks were placed in position on the water-bearing sand and then the inner cylindrical form of the culvert mould was stood upon the block and the space between the form and the clay wall of the well was filled with concrete. This on setting gave a firm foundation on which to continue building the concrete rings one upon the other up to ground level. No fear of subsidence of the well lining is anticipated in this case since the deadweight is resisted greatly by skin-frictional forces between the concrete and the clay walls.

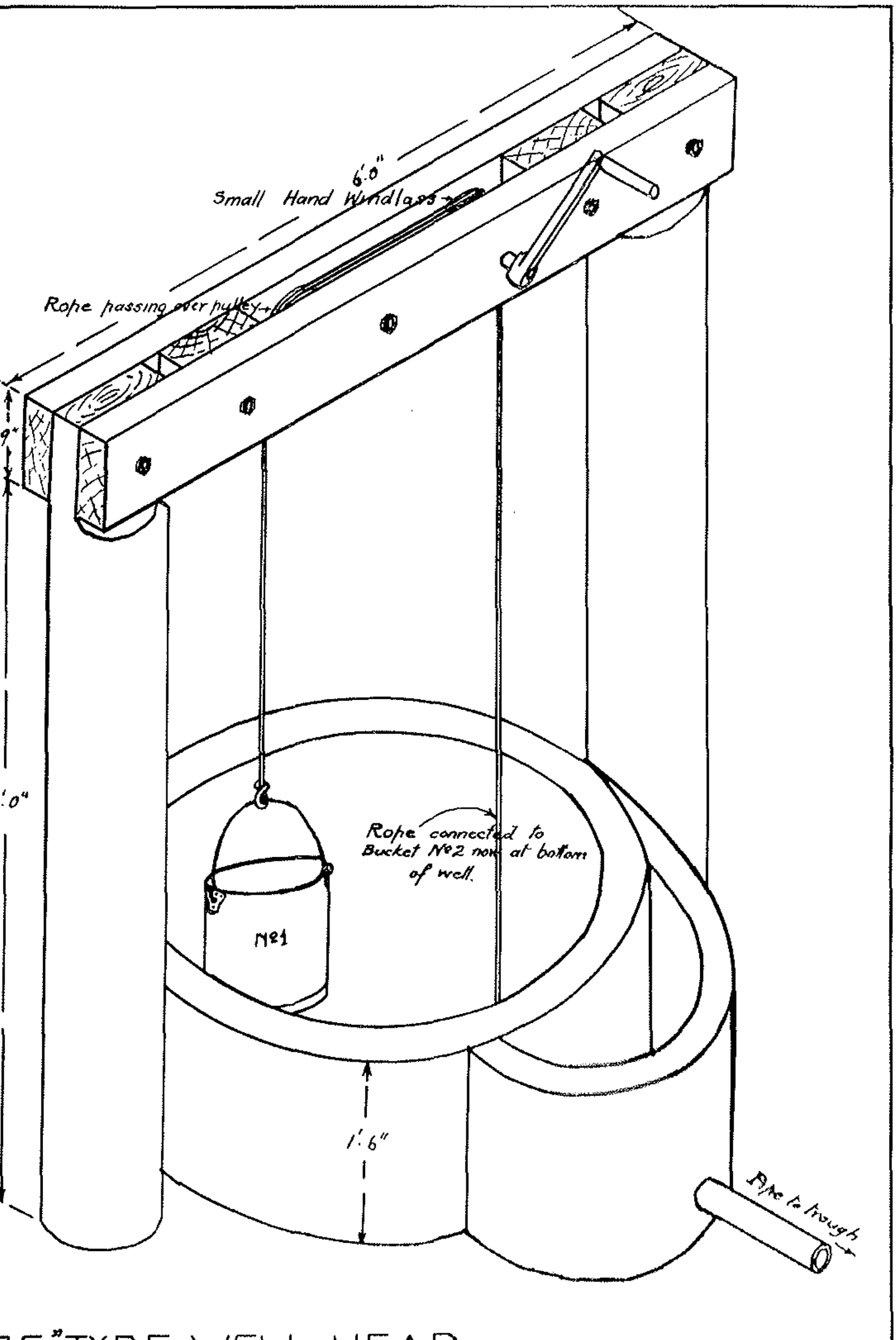
Types of Water-raising Appliances.

Since the inauguration of the water-supply section of the Geological Survey, several types of simple water-raising appliances have been devised and tried experimentally. The primary object aimed at was to arrive at some simple form which would withstand the rough and unintelligent handling to which most Africans subject mechanical appliances. Although the ideal appliance has not yet been discovered, the following types are described and their weak points discussed.

The "Geological Survey" Type Well Head (Plate IV).—This consists essentially of two uprights, one on each side of the well-curbing. The tops of these uprights are joined together by a hollow built-up beam placed horizontally, in which two pulley wheels are placed. One of these rotates freely on its axle, and the other is keyed to its axle and rotates with it. This second pulley is made of cast iron and is actuated by means of a wrought iron handle. Two buckets are used for raising water, and when one is at the surface the other is at the bottom of the well. The buckets are joined together by a wire rope which passes two or three times round the driven pulley and only once over the free pulley. Thus, when it is desired to raise water the handle is turned in the direction which will cause a full bucket to rise, the empty bucket at the top, meanwhile, descending into the well.

As a water-raising gear it works well, but the difficulty has been up to the present to find a wire rope which will not kink badly at the ends nearest the buckets, and which will be flexible enough to remain on the pulleys and not spring off when a bucket is handled for the purposes of emptying. Also, the life of the wire ropes used has been disappointingly short, even when not subjected to excessive kinking and bending. This type was installed at Chandama, Njoro and Mswaki, but at the time of erection only two free pulleys were fitted, the cast iron ones not having been received from the makers. The complete design was afterwards subjected to trial in Dodoma where one was installed over a well from which water was drawn by convicts for use in the prison. After six weeks use the wire rope was practically useless. Chains of different weights are on order for trial purposes with this appliance.

Primitive Hand Windlass (Plate V.).—This type is essentially a rotating barrel supported at each end in suitable bearings by two uprights affixed to foundation sills, and strengthened by struts. The barrel is caused to rotate by pulling on four spokes radiating from it, and to each end of the barrel wire rope is attached in such a way that by rotating in one direction one rope unwinds and the other winds up. Buckets attached to the ropes ends serve to raise water.



— "G.S." TYPE WELL HEAD —

— SCALE $\frac{3}{4}$" = 1 ft. —

G.S. 44.

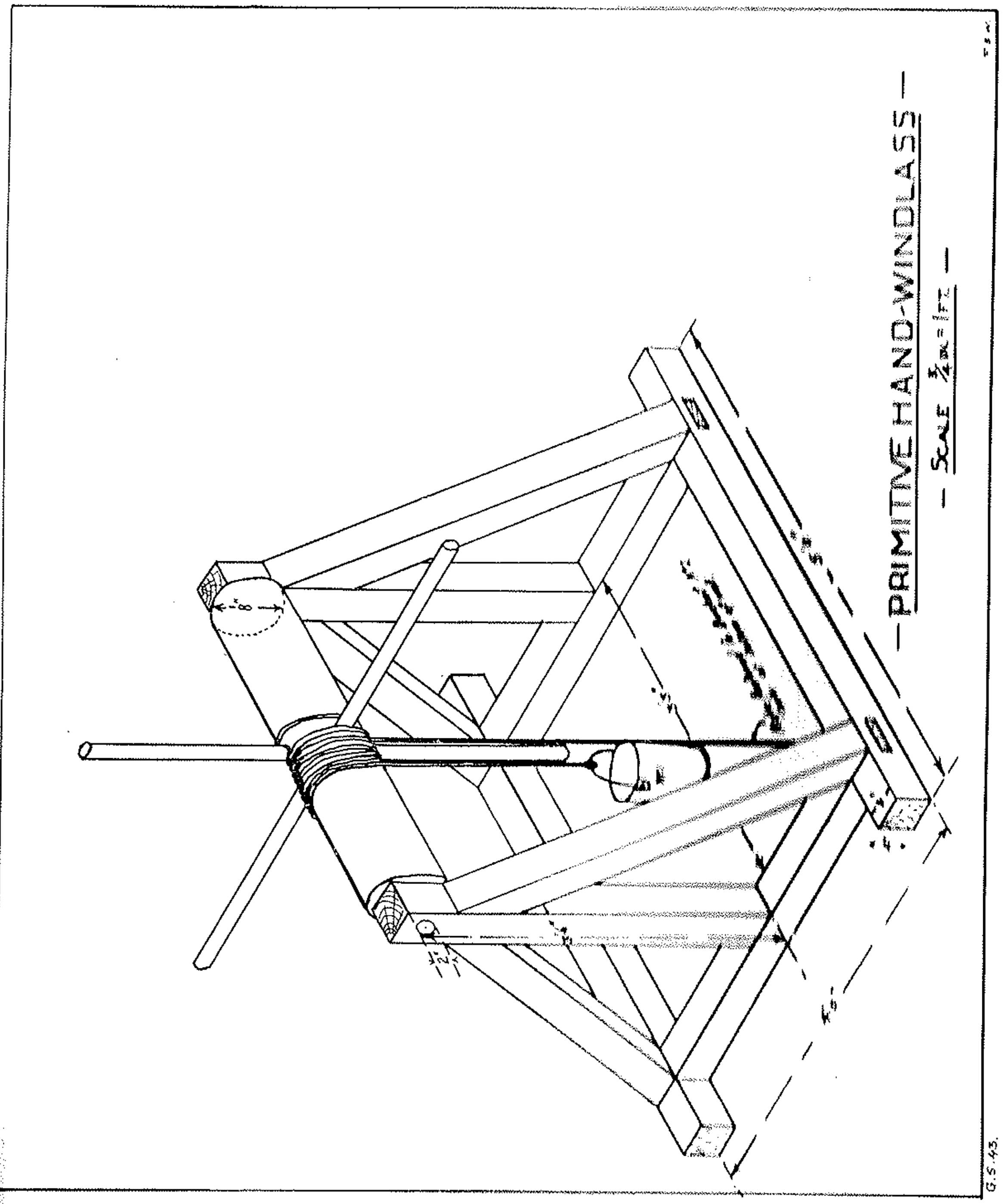
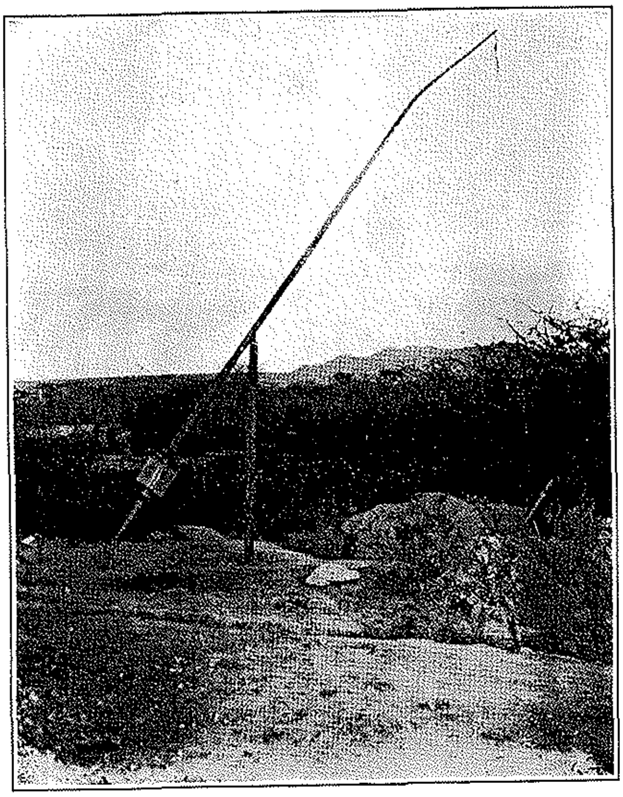

PRIMITIVE HAND-WINDLASS
SCALE ¾ in = 1 ft
G.S. 43.

PLATE VI.



In actual use the wire rope gave trouble as before, and also a defect, due to aiming at simplicity, became obvious in the design. It happened that a native raised one full bucket half way up a 45 feet well and then let go his grip on the spokes. The result was that the barrel rotated with increasing speed and the rapidly rising empty bucket struck the flooring of the well cover causing a sharp strain on the wire and on the barrel and spokes and also damaged the bucket. The result is that the spokes broke one by one, the rope gradually frayed at points of attachment to the barrels and the buckets soon became worthless.

To overcome this defect a ratchet and pawl arrangement would be efficacious but would introduce another complication to befuddle the wits of the native operator. It was thought that this type had been reduced to its simplest proportions, and it is a type that could easily be made by any village native carpenter. Possibly if privately owned it would serve its purpose, but it has proved to be unsuitable in its present form for use at a public well.

The Well Sweep (*Plate VI.*).—This is a type of simple device whereby the weight of the water raised is counterbalanced by a moving weight. The weight of water to be lifted is attached to one end of a lever, and the moving dead-weight is attached to the other end of the lever. and the fulcrum is in between the points of attachment but nearer the dead-weight end. The drawer of water makes the effort to pull down and submerge the bucket, and then with a slight upward pull the momentum of the counterpoise continues the upward motion of the bucket and it arrives at the well mouth with a gradually reducing speed. Its use is widespread among agricultural peoples living as far apart as America and Asia, and in the latter continent it is even used for irrigation purposes.

Its uses are limited to comparatively shallow water supplies, but, like the primitive windlass, it can be made by any native, carpenter or not. The one portrayed is made of scrap piping and a condemned telegraph pole—a relic of the War—and has been functioning without giving trouble since its installation.

Pumps. The Semi-rotary.—This type is known to all and needs no description. One was installed at Kibaya with the object of raising water into a cattle trough and also to supplement the water in a dipping tank. It was not a success owing to the gritty nature of the water raised, and to the unintelligent handling it received.

The Diaphragm Pump.—One of this type has been in use for two years by the Department on various constructional work and is still as good as new. For cattle watering purposes it is excellent provided a large volume of water is available at a relatively shallow depth. The type in use is merely a suction pump, but force pumps of this design can be obtained.

The Ordinary Plunger Pump.—This is a type with which all Europeans should be familiar, since the centre of English country life, the village pump, is of this design. It is the most used pump for bore-holes and deep wells and if properly installed should last for years with but little attention. It is yet to be seen if this minimum of attention is possible by the rural natives.

VIII.—CONCLUSION.

The primary reason for the undertaking described in the foregoing pages was "for the improvement of the water supplies along the Kondoa-Irangi-Handeni cattle route." Before improvements could be effected it was necessary to determine the nature of the existing supplies, and also to investigate the hydrology of the region in order to select sites for new supplies. Three previously existing supplies have been improved, and three new supplies have been found, and two of these converted into permanent wells.

In considering the cattle question in this region, both water and grazing must be found adjacent, and if a well-sinking campaign is undertaken in this vast cattle country, the ordinary dug well has distinct advantages over the deep bore-hole. The dug well generally yields smaller quantities of water than a successful bore-hole, and this limits the number of cattle dependent on one well. If dug wells are made, spaced at suitable distances apart in areas where the hydrological and grazing conditions are uniform, and the number of cattle watered at each well regulated according to its yield, better results should be obtained than if mobs of cattle are concentrated round one successful bore-hole in an equivalent grazing area.

The watering possibilities for trade cattle have not been developed to their full extent along the cattle route, but it is hoped that this report will form a basis on which further improvements can be carried out, and also assist in the development of the Masai country by improving their water supplies and thus ultimately transform them from nomadic pastoralists to a stable tribe of native farmers.