RECORDS OF THE GEOLOGICAL SURVEY OF TANGANYIKA

VOLUME V
1955

CONTENTS

PROGRESS REPORTS AND REGIONAL NOTES

ECONOMIC GEOLOGY

ENGINEERING GEOLOGY

GEOPHYSICS

MINERALOGY AND PETROLOGY

APPENDICES

Engineering Geology

1. GEOLOGY AND UNDERGROUND WATER RESOURCES OF THE MAKUTOPORA DEPRESSION

(Dodoma Water Supply Investigation)

By ALLAN P. FAWLEY, *Mining Geologist*

CONTENTS

ABSTRACT

Drilling in the Makutopora Depression has revealed a maximum thickness of several hundred feet of unconsolidated, or partly consolidated, calcareous, argillaceous and arenaceous sediments overlying weathered granite or gneiss. The weathered granite and gneiss and the calcareous and arenaceous sediments are aquifers and contain a considerable volume of good drinking, though hard, water.

Measurements of the static water level prove: (i) that the sub-surface (ground water) supply is replenished annually; and (ii) that the sub-surface water is continuously flowing towards the north-east.

The maximum amount of water available from deep wells in the Makutopora Depression cannot be determined at present, but a maximum continuous safe yield of 400,000 gallons per day seems assured and there are strong indications that much more than this could be obtained.

I. INTRODUCTION

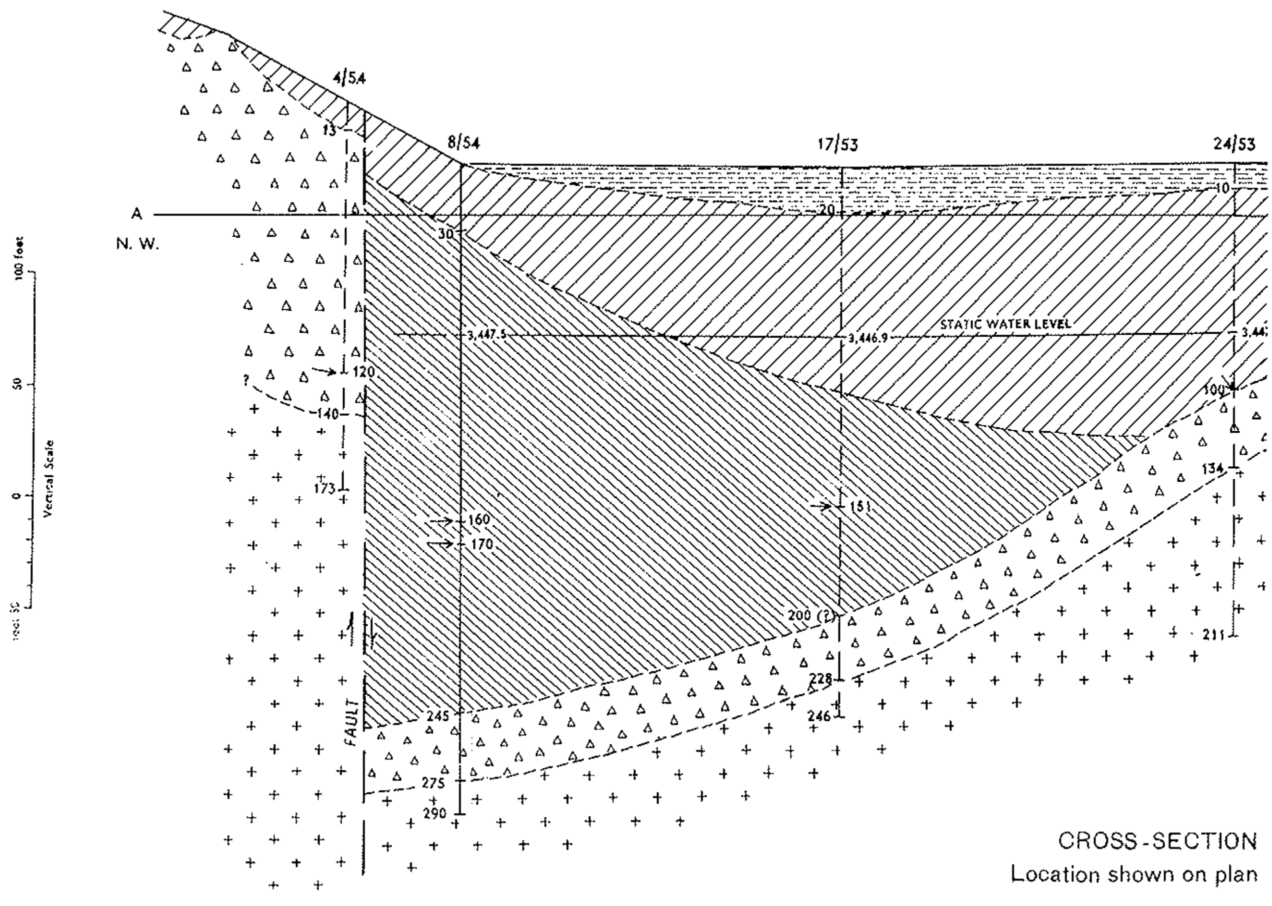
Early history of the water investigation, repeated from preliminary report AF/24, is as follows:—

"The Water Development Department drilled two holes on the north-west flank of the *mbuga*[1] in 1948 and 1951. The first hole yielded 2,400 g.p.h., (gallons per hour) and the second 1,500 g.p.h., with a salinity of only 41 to 43 g.p.g. (grains per gallon). Because of the satisfactory performance of these two holes and on the assumption that similar conditions might overlie the entire *mbuga*, J. C. Lambert (1953) recommended that the *mbuga* be investigated to determine if it would supply 300,000 gallons of water per day.

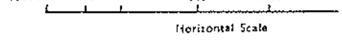
[1] "*Mbuga*" is the local term for a swamp or for a low-lying area that becomes a swamp during the rainy season.

Geology of
Makutopora De[p]

by A. P. Fawley, Geologist,



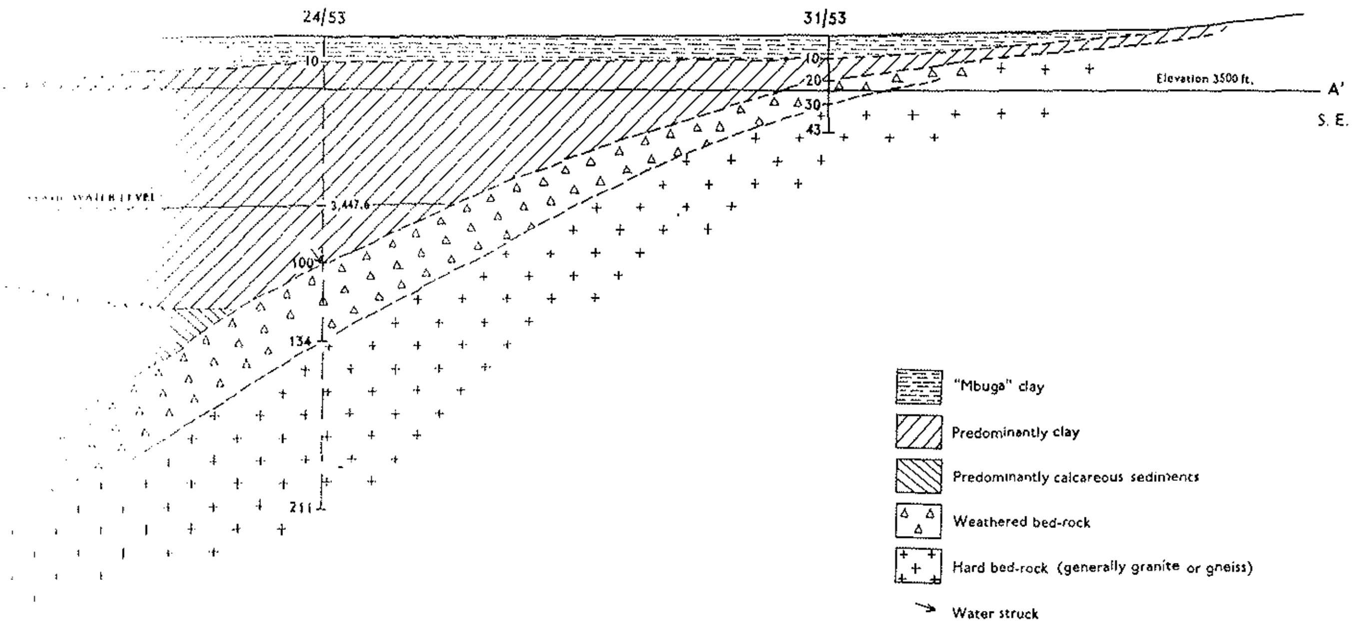
CROSS-SECTION
Location shown on plan



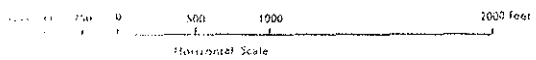
G. S. 727

Geology of the Makutopora Depression

by A. P. Fawley, Geologist, July 1954.



CROSS-SECTION A-A'
Location shown on plan G.S. 726



"Following this recommendation, B.H. 17/53, located within the *mbuga*, was drilled to 246 feet and yielded 4,000 g.p.h. Due to this favourable result the depression area was photographed from the air and a further programme, to test the water possibilities, was laid out by Mr. Bisset, Director of Geological Survey, Messrs. Land and Lambert of the Public Works Department, and the writer."

A total of 13 boreholes[1] have been sunk and tested in the Makutopora Depression and the sub-surface conditions are now fairly well known.

Acknowledgments.—I wish to thank Mr. H. James, of the Water Development and Irrigation Department, for carefully collecting samples at five-foot intervals during drilling; Mr. J. Ambrose, of the Public Works Department, for accurately recording the drawdowns and yield during extended pumping tests and Mr. F. M. Coster, Engineering Geologist, Water Development and Irrigation Department, for courteous assistance on several problems.

II. Location and Surface Conditions

The lowest part of the Makutopora Depression is overlain by an elongated *mbuga* covering seven square miles. The *mbuga* is about 15 miles north of Dodoma. About one-third of the *mbuga* surface was flooded during the heavy rains of December 1953, and some of this area remained covered with water until May 1954. The entire *mbuga* surface was dry by 25th May, 1954.

III. Geology

The sub-surface geology is shown on cross-sections (see Plates VIII and IX), and the area covered by the *mbuga* and the location of the Mlemu Fault are shown on Plate X.

The Mlemu Fault extends south-westwards from the Makutopora Depression to Kigwe, a distance of more than 15 miles. It has a throw of about 260 feet near B.H. 4/54. The amount of horizontal movement is not known. The approximate location of the fault at Makutopora was determined by drilling (the exact location is not known, but the fault lies between B.H. 4/54 and B.H. 43/53); its continuation to Kigwe can be observed on air photographs. The fault probably dips vertically or at a very steep angle.

The sub-surface geology has been interpreted from the sludge and rock-fragments obtained by boring with a churn drill, which is not nearly as satisfactory as when solid core can be obtained. However the boundaries between the various rock types, as shown on the cross-sections, are probably accurate to within a few feet in most cases.

A brief description of the various rock classifications used for the cross-section and longitudinal section follows:—

(a) *Mbuga* Clay

Mbuga clay (also called "Black Cotton" soil or clay) is plastic when wet. On drying it becomes hard and brittle and is dark grey. In places it is calcareous and/or sandy.

An analysis of *mbuga* clay from B.H. 35/53, depth 0–20 feet, yielded the following results:—

SiO_2 Per cent	R_2O_3 (Insoluble) Per cent	R_2O_3 (Soluble) Per cent	CaO Per cent	MgO Per cent	Undetermined Per cent	Loss on ignition Per cent	Total Per cent
45·0	9·5	20·5	1·6	1·6	3·8	18·0	100·0

(R_2O_3 estimated to be 83 per cent Al_2O_3 and 17 per cent Fe_2O_3)

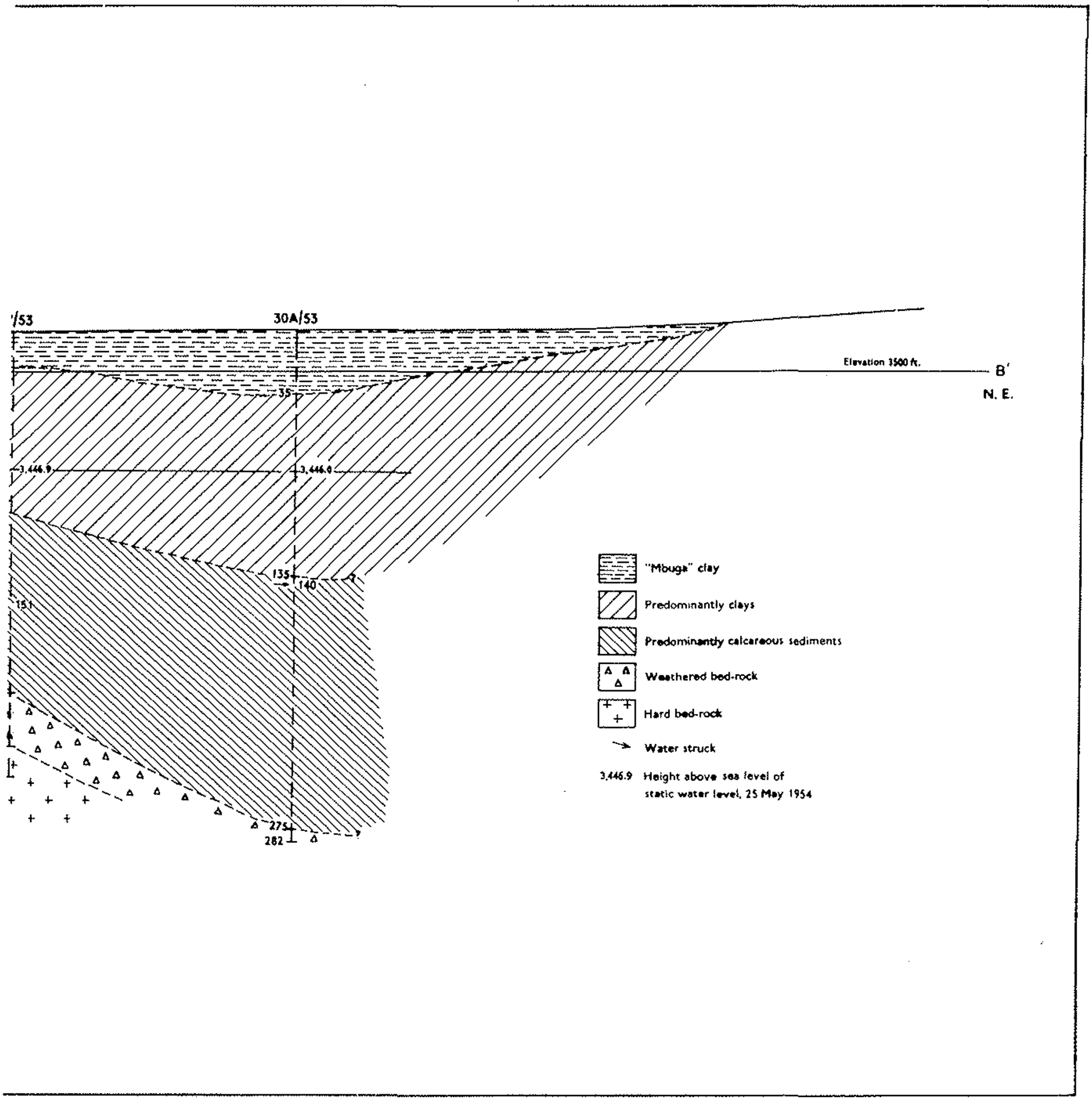
Analyst: W. K. L. Thomas, Geological Survey of Tanganyika.

(b) Predominantly Clays

This category includes light-coloured clays, claycrete, and some calcrete. The clays are often calcareous or contain considerable colloidal silica.

[1]Deep water wells in Tanganyika are customarily called "boreholes" (B.H.) and the Tanganyika terminology for such wells is used throughout this report. All except the deeper sections of B.H. 12/48 and B.H. 34A/51 are eight inches in diameter.

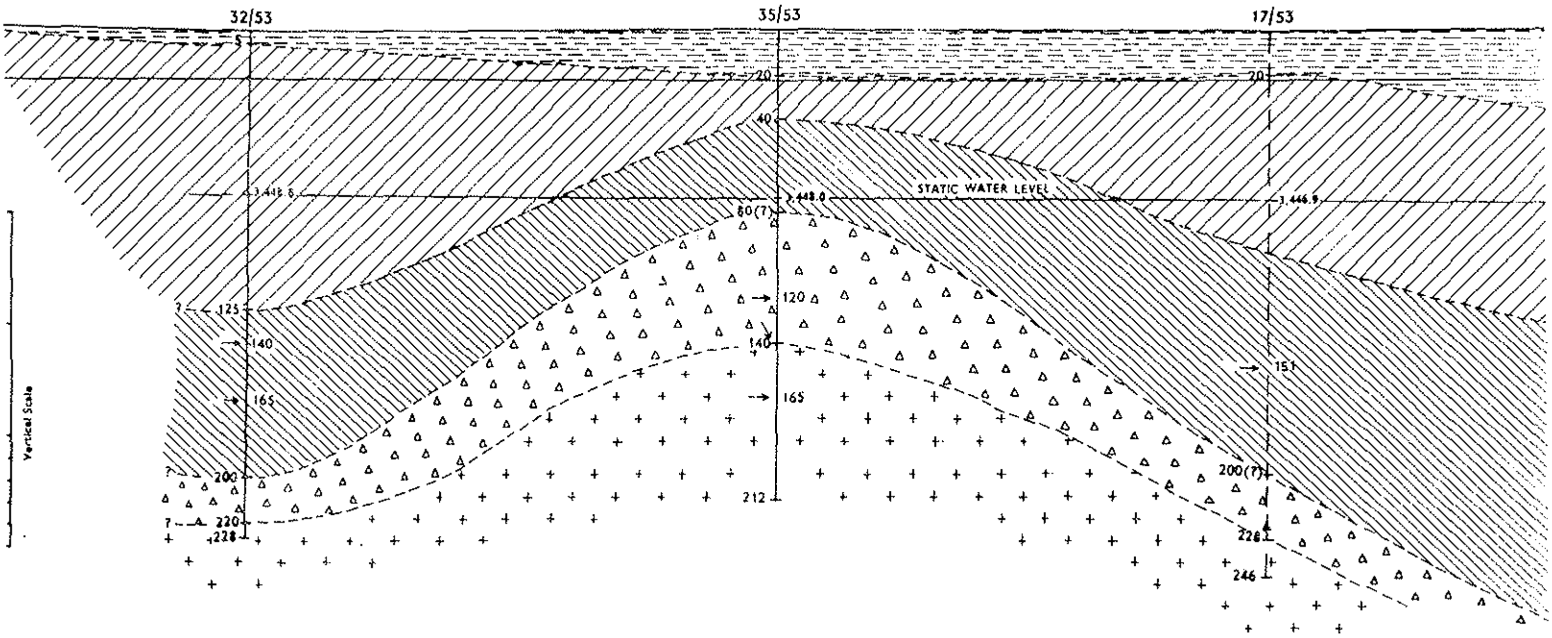
Plate IX



Geological Survey Department, Dodoma 1954.

Geology of the Makutopora Depression

by A. P. Fawley, Geologist, July 1954.



LONGITUDINAL SECTION B-B'

Location shown on Plate X

the depression area
water possibilities,
nd and Lambert of

topora Depression

ater Development
tervals during drilling
cording the drawdown
Engineering Geologist
e on several problems

an elongated *mbuga*
of Dodoma. About
December 1953, and
entire *mbuga* surface

II and IX), and the
own on Plate X.

epression to Kigwe
ar B.H. 4/54. The
tion of the fault
own, but the fault
be observed on all

fragments obtained
a solid core can be
as shown on the

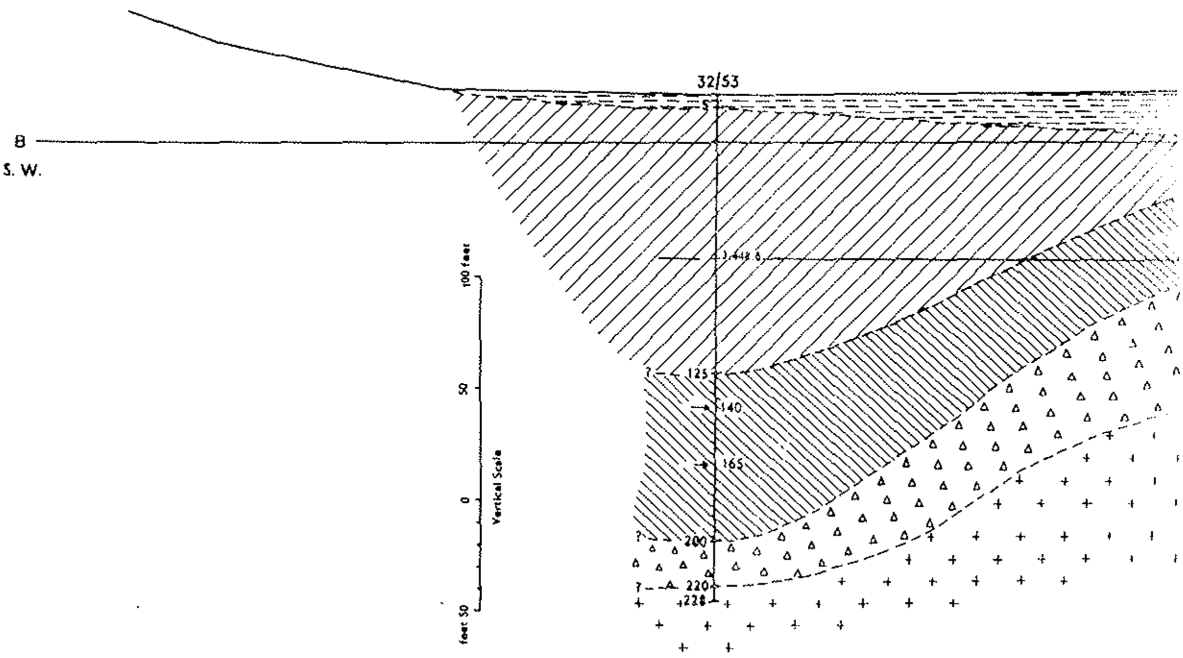
cross-section and

wet. On drying
nd/or sandy.
ed the following

oss on nition r cent	Total Per cent
8·0	100·0

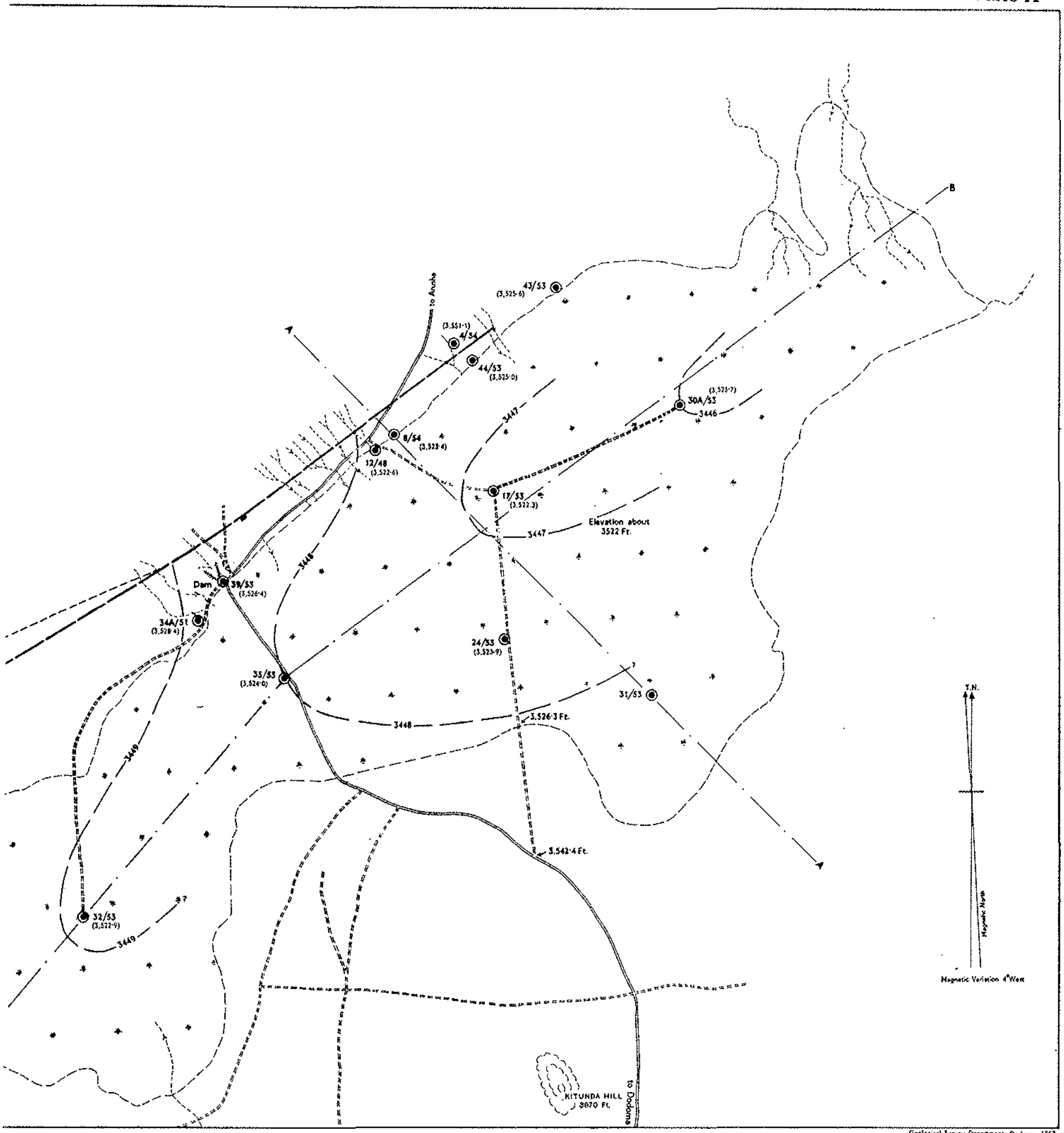
ite. The clay

nyika terminology
. 12/48 and B.H.



G. S. 729

Plate X



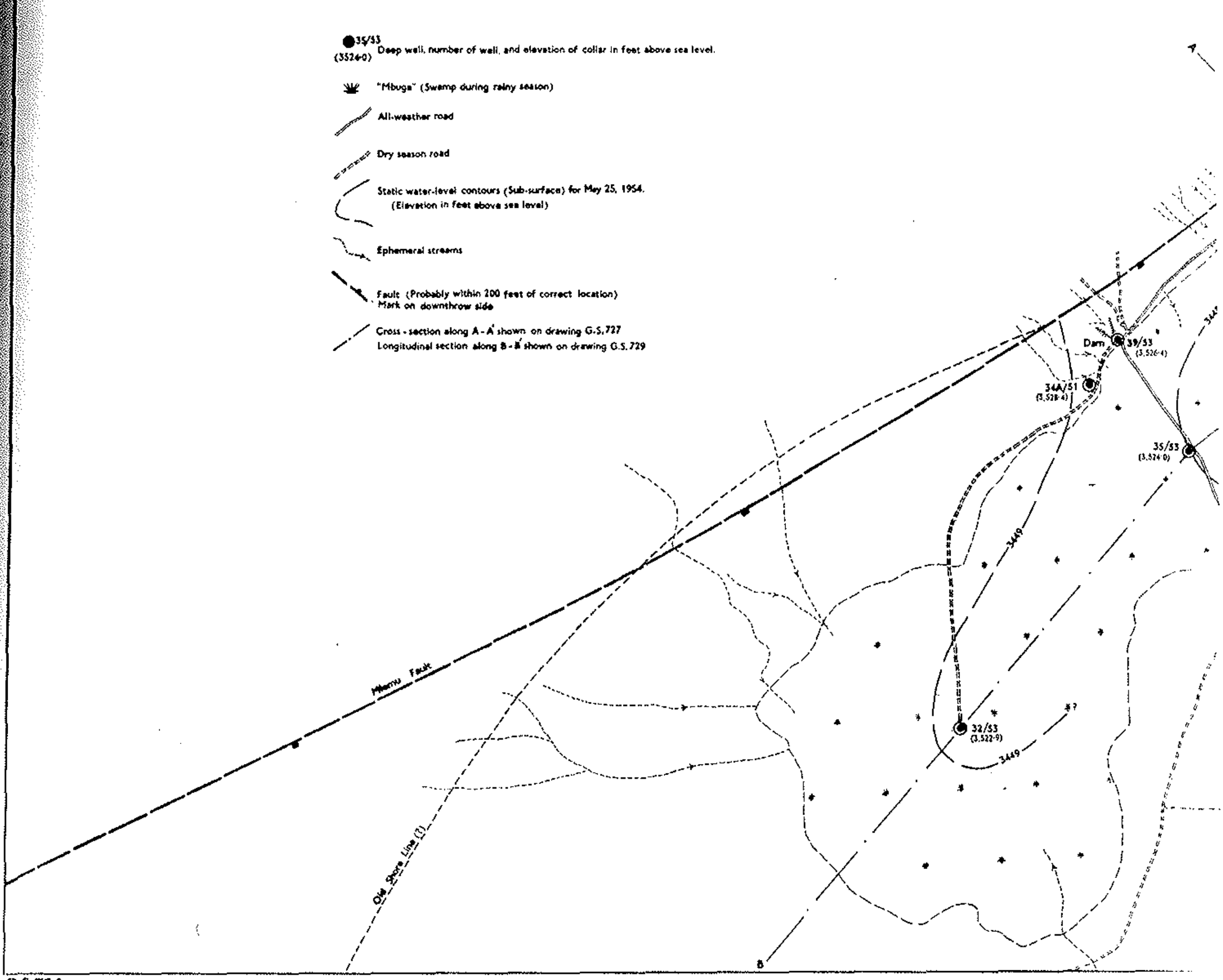
Geological Survey Department, Dodoma, 1957

MAKUTOPORA DEPRESSION
DODOMA WATER SUPPLY INVESTIGATION

by Allan P. Fawley, July, 1954.

Scale

Feet 1000 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10,000 Feet



G.S.726

"Claycrete" and "calcrete" are terms used for distinctive types of sediments which are largely composed of grains of quartz cemented together with clay or calcite; mica and other femic minerals are almost completely absent. Claycrete is generally light olive-grey and is bound together by clay, while calcrete is generally white or light-yellowish grey and is cemented together by calcite. The quartz content of both claycrete and calcrete ranges from about 20 to 70 per cent, the quartz grains are sub-rounded to angular and average about 1/16 in. in diameter. (When the quartz grains average about ¼ in. the rock is called a cemented or calcareous gravel).

An analysis of a sample of calcareous clay from B.H. 30A/53, depth 25–135 feet, follows:—

SiO_2 (Insoluble) Per cent	R_2O_3 (Insoluble) Per cent	R_2O_3 (Soluble) Per cent	CaO Per cent	MgO Per cent	Loss on ignition Per cent	Total Per cent
44·8	9·7	18·2	6·1	1·3	19·8	99·9

Analyst: J. Saileni, Geological Survey of Tanganyika.

(c) Predominantly Calcareous Sediments

This category includes limestone, siliceous limestone, calcrete, calcareous gravel, and some calcareous clay and claycrete.

The limestone at Makutopora is of a very siliceous type. It is white or very light-coloured and is similar in nature and origin to calcrete. An empirical division has been made between limestone and calcrete; rocks with considerable calcite and less than 20 per cent visible quartz grains[1] are called "limestone", while those with considerable calcite but more than 20 per cent visible quartz grains are called "calcrete". The rock called "siliceous limestone" contains less than 20 per cent visible quartz but is high in colloidal silica.

Analyses of rocks classified as limestone, or siliceous limestone, follow. (It should be noted that some rocks classified as "limestone" by visual methods, and tested with acid, have been named erroneously).

(i) White "limestone" from B.H. 30A/53 containing 5 per cent visible quartz—depth 150-186 feet.

SiO_2 (Insoluble) Per cent	R_2O_3 (Insoluble) Per cent	R_2O_3 (Soluble) Per cent	CaO Per cent	MgO Per cent	Loss on ignition Per cent	Total Per cent
23·0	1·6	2·6	38·9	0·3	33·5	99·9

Analyst: J. Saileni, Geological Survey of Tanganyika.

(ii) White "limestone" from B.H. 39/54 containing 10 per cent visible quartz—depth 40-55 feet.

SiO_2 (Insoluble) Per cent	R_2O_3 (Insoluble) Per cent	R_2O_3 (Soluble) Per cent	CaO Per cent	MgO Per cent	Undetermined (Insoluble) Per cent	Loss on ignition Per cent	Total Per cent
41·3	9·0	3·0	12·9	1·8	13·5	18·4	99·9

(Moisture content in loss on ignition 3·4 per cent)

Analyst: W. K. L. Thomas, Geological Survey of Tanganyika.

[1] The various rock types were all examined under a low-power binocular microscope. Quartz grains listed as "visible' have a minimum diameter of about 0·1 mm.

(iii) The first of the following three samples was classified as "siliceous limestone with 15 per cent visible quartz", the second as "white limestone with 5 per cent visible quartz", and the third as "white limestone with 3 per cent visible quartz".

Borehole	Depth in feet	R_2O_3 (Soluble) Per cent	CaO Per cent	MgO Per cent	Undetermined (Insoluble) Per cent	Loss on ignition Per cent	Total Per cent
B.H. 43/53	30–50	9·1	6·8	0·9	69·4	13·8	100·0
8/54	155–165	7·2	15·9	1·0	51·7	22·7	98·5
8/54	175–215	3·1	34·0	0·8	29·2	31·7	98·8

Analyst: J. Saileni, Geological Survey of Tanganyika.

(d) Weathered Bed-rock

The bed-rock penetrated is generally hornblende gneiss, granite, or alaskite (a variety of granite). The weathered bed-rock zone may be more than 100 feet thick.

(e) Hard Bed-rock

The weathered bed-rock gradually became harder at depth and, empirically, when the drilling speed of the churn drill was reduced to a few feet per day the rock was classified as "hard" bed-rock.

IV. Note on Rainfall at Makutopora

No rain gauge is installed at the Makutopora Depression; however, the average rainfall is probably similar to that at Dodoma, which has a 24-year average of 22·93 inches:[1]

The rainy season of 1952-53 was exceptionally poor and only about 10 inches of rain fell. The 1953-54 rainy season started on December 17th and about 8 inches of rain fell in the latter half of that month; during January, February and March there were only light rains, but the season ended with heavy rains early in April.

V. Borehole Logs

All the boreholes except B.H. 12/48 and B.H. 34A/51 were logged by the writer (G.S.D Notebook No. 17 of A. P. Fawley). Definitions of terms such as "calcrete" have already been given under "Geology". A summary of the logs follows:—

B.H. 12/48:
feet
0–208 marl, clays, limestone;
208–232 calcrete;
Water struck at a depth of 156 ft.

B.H. 34A/51:
feet
0–184 clays, marls, granite brash;
Water struck at depths of 82 and 181 ft.

B.H. 17/53:
feet
0– 20 *mbuga* clay and calcareous clay;
20–150 claycrete and siliceous and calcareous clays;
150–165 calcrete and cemented gravel;
165–200(?) claycrete and calcrete;
200(?)–228 weathered gneiss;
228–246 partly weathered hornblende gneiss;
p– 45 Water struck at a depth of 151 (?) ft.

[1]East African Meteorological Department. 1953. Summary of Rainfall for the year 1952. Part II, Tanganyika.

B.H. 24/53:

feet
0– 10 *mbuga* clay;
10– 15 clay;
15– 30 calcareous clay;
30– 55 siliceous clay;
55– 82 claycrete;
82– 96 lost core (due to boulder);
96–100 sandy claycrete;
100–134 weathered granite;
134–208 partly weathered hornblende-biotite granite (fractured zone 190 195ft.);
208–211 hornblende granite;
Water struck at a depth of 100 ft.

B.H. 30A/53:

feet
0– 35 *mbuga* clay;
35– 50 clay;
50–135 calcareous clay;
135–186 limestone;
186–255 calcrete;
255–275 cemented calcareous gravel;
275–282 partly weathered bed-rock;
Water struck at a depth of 140 ft.

B.H. 31/53:

feet
0– 10 *mbuga* clay;
10– 20 claycrete;
20– 30 weathered alaskite;
30– 43 partly weathered alaskite and granite;
Drilling stopped before water horizon reached.

B.H. 32/53:

feet
0– 5 *mbuga* clay;
5–125 clay, part calcareous clay;
125–135 calcrete and limestone;
135–150 claycrete;
150–160 limestone;
160–200 calcrete, gravel in part;
200–220 weathered alaskite;
220–228 alaskite;
Water struck at depths of 140 and 165 ft.

B.H. 35/53:

feet
0– 20 *mbuga* clay;
20– 40 clay;
40– 80 calcrete;
80–115 decomposed mica gneiss (?);
115–140 weathered gneiss;
140–212 hornblende-biotite granite;
Water struck at depths of 120, 140, and 165 ft.

B.H. 39/53:

feet
0– 15 sandy calcareous clay;
15– 25 calcareous claycrete;
25– 75 calcrete and limestone;

B.H. 39/53:—(*contd.*)

feet	
75–100	calcareous claycrete;
100–120	sandy calcrete;
120–130	limestone and clay;
130–155	cemented calcareous gravel;
155–175	calcrete (?) or decomposed bed-rock (?);
175–250	weathered hornblende granite;
250–255	hornblende granite;

Water struck at depths of 105 and 125 ft.

B.H. 43/53:

feet	
0–110	calcrete;
110–130	claycrete;
130–135	cemented gravel;
135–150	claycrete;
150–180	clay-gravel mixture;
180–195	calcrete;
195–205	cemented gravel;
205–220	calcrete;
220–250	cemented gravel;

Water struck at depths of 117 and 160 ft.

B.H. 44/53:

feet	
0– 30	claycrete;
30–145	calcrete;
145–180	cemented gravel;
180–210	calcrete;
210–215	cemented calcareous gravel;
215–240	calcrete;
240–243	cemented calcareous gravel;

Water struck at a depth of 160 ft.

B.H. 4/54:

feet	
0– 13	claycrete and sandy soil;
13–140	weathered granite and alaskite;
140–173	alaskite;

Water struck at a depth of 120 ft.

B.H. 8/54:

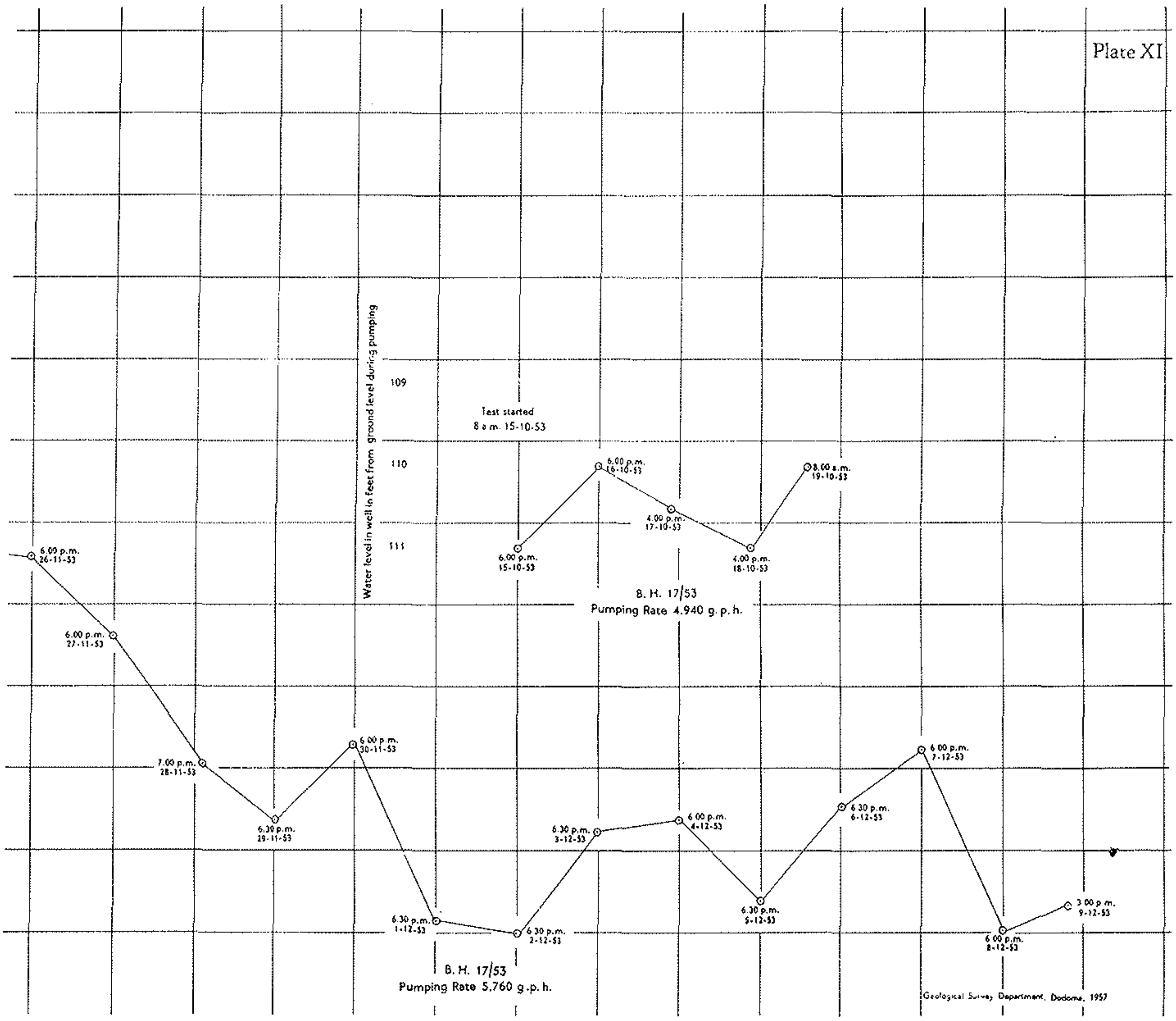
feet	
0– 30	sandy clay and claycrete;
30–105	calcrete;
105–155	calcareous clay;
155–175	siliceous limestone;
175–215	limestone;
215–245	calcrete;
245–275	weathered gneiss (?);
275–290	granite and gneiss;

Water struck at depths of 160 and 170 ft.

VI. Pumping Tests

The largest pump available had a yield of only 6,000 g.p.h. (gallons per hour) and it was not possible, therefore, to pump the more successful boreholes at capacity. Yields and drawdowns obtained from the various pumping tests are listed below—each drawdown is that obtained at the end of the test period. These results have also been plotted on a

Plate XI

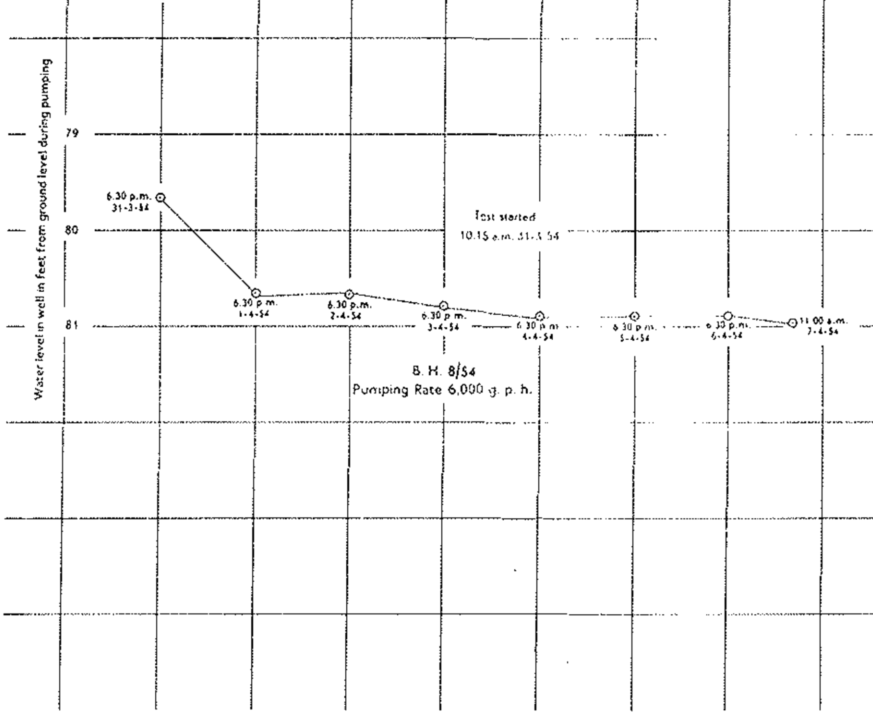


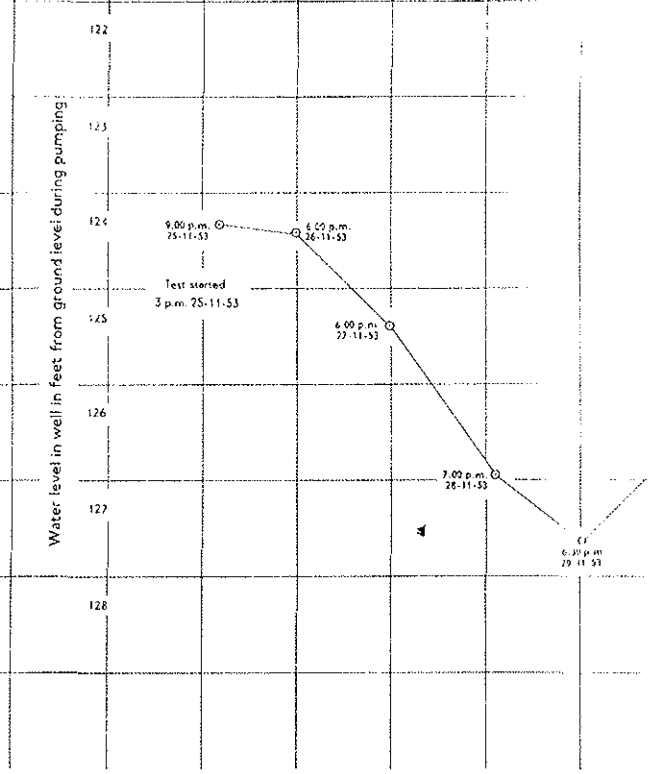
Geological Survey Department, Dodoma, 1957

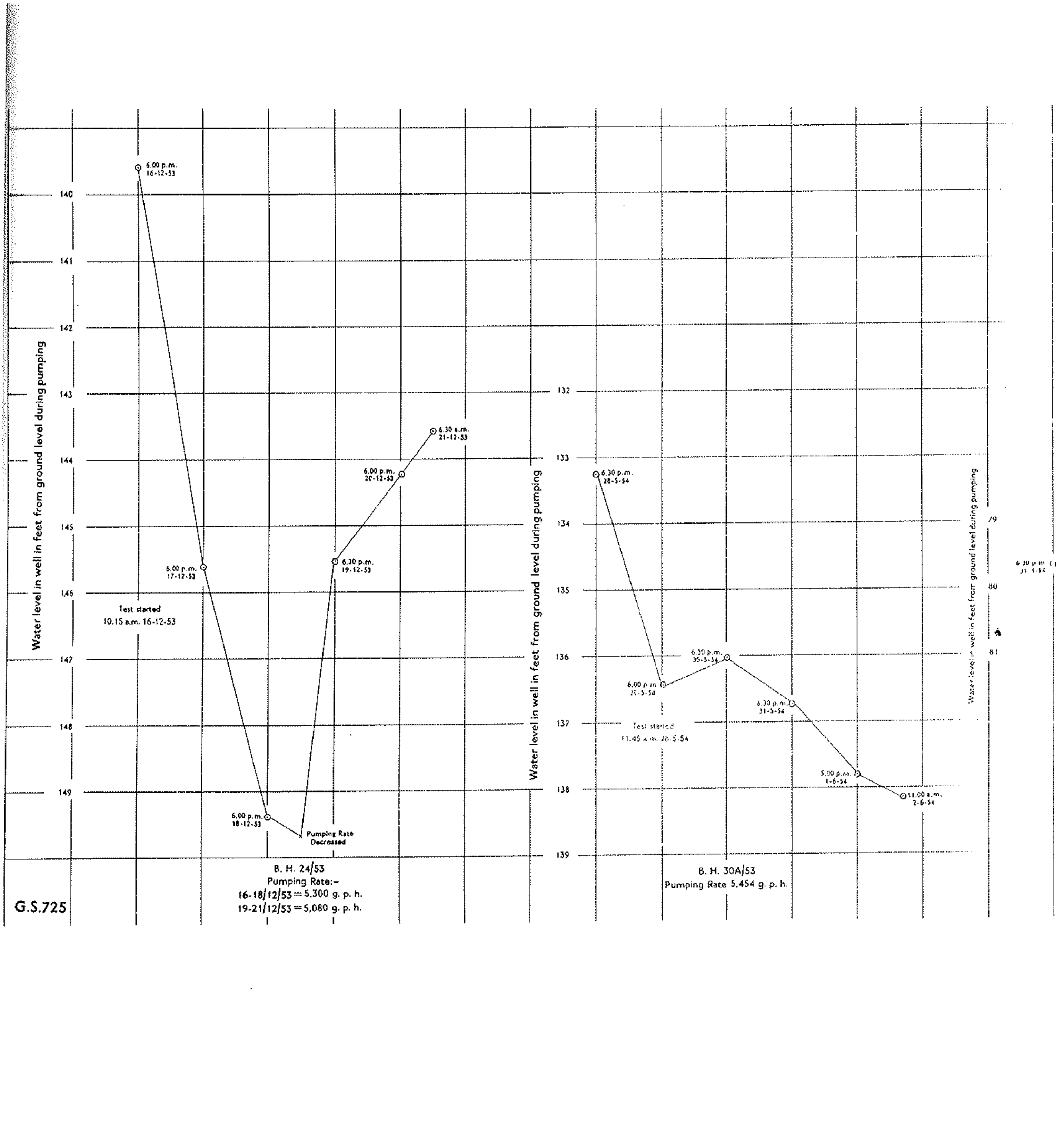
Pumping Tests of some Wells in the Makutopora Depression

Showing changes in drawdown during continuous pumping at a constant rate

Tests conducted by J. Ambrose, Public Works Department.
Graphs drawn by A.P. Fawley, Geologist,
Geological Survey Department, July 1954






Water level in well in feet from ground level during pumping
140
141
142
143
144
145
146
147
148
149
6.00 p.m. 16-12-53
6.00 p.m. 17-12-53
6.00 p.m. 18-12-53
Pumping Rate Decreased
6.30 p.m. 19-12-53
6.00 p.m. 20-12-53
6.30 a.m. 21-12-53
Test started 10.15 a.m. 16-12-53
B. H. 24/53
Pumping Rate:–
16-18/12/53 = 5,300 g. p. h.
19-21/12/53 = 5,080 g. p. h.
Water level in well in feet from ground level during pumping
132
133
134
135
136
137
138
139
6.30 p.m. 28-5-54
6.00 p.m. 29-5-54
6.30 p.m. 30-5-54
6.30 p.m. 31-5-54
5.00 p.m. 1-6-54
11.00 a.m. 2-6-54
Test started 11.45 a.m. 28-5-54
B. H. 30A/53
Pumping Rate 5,454 g. p. h.
Water level in well in feet from ground level during pumping
79
80
81

G.S.725

graph (Plate XI) from which any drawdown can be rapidly obtained. Changes due to drawdown during continuous pumping at a constant rate are shown on Plate XIII.

Borehole	Volume in g.p.h.	Drawdown in ft.	Duration of test in hours
12/48	2,500	27(?)	10
34A/51	800	17	0·75
	1,760	45	4
17/53	3,200	16	4
	3,750	19	8
	4,940	32	100
	5,760	51	336
17/53 (re-test)	4,000	24·5	0·25
	4,736	32·4	0·75
	5,454	39·3	1
	5,454	41·6	4
	5,454	41·1	42
24/53	3,750	40(?)	36
	4,300	56(?)	4
	5,080	68	120
30A/53	1,000	5·8	0·5
	1,565	10·3	0·5
	2,571	19·2	0·5
	3,461	26·6	0·5
	4,285	37·2	1
	5,454	52·1	1
	5,454	55·5	24
	5,454	59·8	120
31/53	Nil	—	—
32/53	4,000	47	36
35/53	1,500	120 (approx.)	48
39/53	1,750	135 (approx.)	48
43/53	1,200	135 (approx.)	48
44/53	540	152	0·75
	450	111	6
	460	135	20
	670	90*	11
4/54	160†	65(?)	4
8/54	1,560	1	1
	2,310	1·5	1·5
	3,300	2·3	1·75
	3,600	2·5	22
	4,260	3·3	2·25
	4,900	4	2·5
	5,400	4·3	3
	6,000	5	168

*Borehole surged and cleaned out before this test.
†A bailing test.

VII. Elevations of Borehole Collars

The following elevations have been obtained by converting the surveying results of Messrs. Lambert and Lineham of the Public Works Department to sea level.

Borehole	Ground elevation in feet	Elevation of top of casing in feet
12/48	3,522·6	3,524·9
34A/51	3,528·4	3,528·7
17/53	3,522·3	3,523·2(?)
24/53	3,523·9	3,525·6
30A/53	3,523·7	3,524·4(?)
32/53	3,522·9	3,524·5
35/53	3,524·0	3,526·1
39/53	3,526·4	3,527·4(?)
43/53	3,525·6	no casing
44/53	3,525·0	no casing
4/54	3,551·1	no casing
8/54	3,523·4	3,524·9

VIII. Static Water Level

The following table records the elevation of the static water level above sea level at various periods since the boreholes were completed. It will be noted that (i) the elevation falls during the dry season and rises during the wet season; and (ii) that the elevations in 1954 are about two feet higher than they were in 1948 and 1951.

The static water level contours for May 25th, 1954, are shown on Plate X.

Borehole	Date	Elevation of static water level in feet
B.H. 12/48	1948	3,444
	22 Aug. 1953	3,446
	7 Apr. 1954	3,447·6
34A/51	1951	3,446
	3 Oct. 1953	3,448·2
	18 Dec. 1953	3,447·4
	7 Apr. 1954	3,449·1
	25 May, 1954	3,448·6
	9 July, 1954	3,448·6
17/53	3 Oct. 1953	3,446
	16 Dec. 1953	3,444·8
	30 Mar. 1954	3,446·7
	25 May, 1954	3,446·9
	9 July, 1954	3,446·7
24/53	3 Oct. 1953	3,446·9
	18 Dec. 1953	3,445·9
	30 Mar. 1954	3,447·4
	25 May, 1954	3,447·6
	9 July, 1954	3,447·4
30A/53	18 Dec. 1953	3,444·6
	30 Mar. 1954	3,445·7
	25 May, 1954	3,446·1
	9 July, 1954	3,446·0
32/53	24 Nov. 1953	3,447·7
	18 Dec. 1953	3,447·5
	30 Mar. 1954	3,448·7
	25 May, 1954	3,448·8
	8 June, 1954	3,448·8
	9 July, 1954	3,448·6
35/53	26 Oct. 1953	3,446
	18 Dec. 1953	3,445·3
	5 Jan. 1954	3,446·7
	28 Jan. 1954	3,447·6
	30 Mar. 1954	3,448·1
	7 Apr. 1954	3,448·2
	14 Apr. 1954	3,448·1
	25 May, 1954	3,448·0
	8 June, 1954	3,447·9
	9 July, 1954	3,447·9
39/53	18 Dec. 1953	3,447·2
	7 Apr. 1954	3,448·8
	25 May, 1954	3,448·6
	8 June, 1954	3,448·4
	9 July, 1954	3,448·3
43/53	5 Jan. 1954	3,446·6
44/53	28 Dec. 1953	3,445·9
	21 Jan. 1954	3,446·4
	2 Feb. 1954	3,446·7
4/53	2 Feb. 1954	3,447
8/53	30 Mar. 1954	3,447
	14 Apr. 1954	3,447·4
	25 May, 1954	3,447·5
	8 June, 1954	3,447·4
	9 July, 1954	3,447·3

IX. Water Analyses from Makutopora Boreholes

Analyses of water from the various boreholes sunk in the Makutopora Depression are given on Plate XII. These analyses were done under the supervision of Mr. R. A. [illegible]ilton, Geochemist, Geological Survey of Tanganyika; they indicate that, with the exception of B.H. 39/53 and B.H. 4/54, all the water has been derived from a similar source. (Water from B.H. 39/53 and B.H. 4/54 has a higher proportion of common salt than from the other boreholes). The water is clear and nice tasting, but hard. The temperature of the water, taken after pumping for one hour from B.H. 12/48 on June 8th, 1953, was 82°F.

The following analyses are by the Chemical Laboratory, Dar es Salaam:—

1. Analysis of "Makutopora Water" (probably from B.H. 12/48) Dec. 1953.
(p.p.m.—parts per million)
pH 7·3

Total hardness (as $CaCO_3$)	242	p.p.m.
Total alkalinity (as $CaCO_3$)	396	p.p.m.
Free carbon dioxide	6·6	p.p.m.

On the basis of the above analysis, the Chemical Laboratory reported "Hence the water is non-corrosive".

2. Analysis of water from B.H. 17/53, July, 1953.

Turbidity	Clear	
pH 8·1		
Total solids	782	p.p.m.
Total hardness	253	p.p.m.
Alkalinity	428	p.p.m.
Sodium bicarbonate	175	p.p.m.
Chlorides	76	p.p.m.
Free ammonia	0·014	p.p.m.
Alb. ammonia	0·122	p.p.m.
Nitrates	Trace	
Nitrites	Nil	
Heavy metals (Cu, Pb, Sn.) ...	Absent	
Oxygen absorbed	0·5	p.p.m.

X. Borehole Yields

The yield actually obtained from the various boreholes is tabulated in an earlier section "Pumping Tests" and is also shown on Plate XIII.

Five of the boreholes, B.H. 17/53, B.H. 24/53, B.H. 30A/53, B.H. 32/53 and B.H. 8/54 have a maximum yield of more than 4,000 gallons per hour, and B.H. 12/48 may also be in this category. All of the above, except B.H. 12/48, were drilled deep enough to penetrate through the sediments to bed-rock.

B.H. 34A/51, B.H. 35/53, and B.H. 39/53 have a maximum capacity of only 1,000 to 2,000 gallons per hour, apparently partly due to a saddle in the bed-rock in this area (see longitudinal section, Plate IX).

B.H. 43/53 and B.H. 44/53 yielded only 1,200 and 670 gallons per hour respectively. This low yield was very disappointing as they were drilled in geologically favourable areas. Both of these holes were stopped due to mechanical difficulties before they had penetrated to bed-rock. It is probable that if they had been deepened to bed-rock, they would have yielded more than 4,000 gallons per hour.

B.H. 31/53 was drilled to determine the depth to bed-rock and was stopped before the water-bearing horizon was reached.

B.H. 4/54 was drilled to help determine the location of the Mlemu Fault and the direction of flow of the sub-surface water.

The yield for drawdowns of 30 to 60 feet (i.e. to depths of 110 to 140 feet below the *mbuga* surface) for the boreholes in which casing has been left is given below. The figures were obtained from the graph on Plate XI. B.H. 12/48 is not included as drawdown figures are not available.

Drawdown in feet	30	40	50	60
Borehole	Yield in gallons per hour			
B.H. 35/53	880	1,020	1,100	1,180
39/53	950	1,120	1,220	1,290
34A/51	1,250	1,520	1,710	1,860
24/53	3,100	3,600	4,120	4,600
32/53	3,100	3,600	4,120	4,600
30A/53	3,650	4,400	5,000	5,510
17/53	4,580	5,300	5,800	6,200
8/54	11,000+	12,000+	12,500+	13,000+
Total	28,510+	32,560+	35,570+	38,240+

XI. Water Bearing Strata

Unfortunately pumping tests could not be obtained for the different types of strata encountered during drilling within each borehole but were only made when the borehole was completed. Hence the amount of water that can be obtained from the different rock strata can only be estimated.

Water in appreciable quantities was not struck until depths of 100 to 180 feet were reached so there is little available water in the clay and predominantly clay zones.

The predominantly calcareous sediments and the weathered bed-rock are both aquifers and both yield a considerable volume of water. Some fissures probably occur within the bed-rock which will also give a considerable volume of water. The most prolific horizon appears to be at the contact of the weathered bed-rock with the overlying sediments.

XII. Natural Recharge of Aquifers

Contours of the static water level (see Plate X) show that the water pressure decreases to the north-east end of the depression and hence the sub-surface waters must flow out in this direction. Since water is flowing out but the static water level is even higher now than in 1948, water must be flowing in to the sub-surface supply.

XIII. Origin of the Sub-Surface (Ground) Water

Soils surrounding the Makutopora Depression have been largely derived from granite and are sandy and porous. A large surface run-off does not occur in this area. During heavy rains, a considerable proportion of the rainfall probably penetrates to depths too great for evaporation or transpiration; this water would slowly migrate towards the under-ground supply below the Makutopora Depression. When the *mbuga* is flooded, some water undoubtedly seeps downwards but, due to the thick clay cover at Makutopora, the amount reaching the aquifer must be small in comparison with the amount of water entering by means of the sandy soils that surround the *mbuga*.

Water may also enter the underground supply in the depression area by means of the Mlemu Fault which lies along the north-west side of the depression and extends from the depression for a distance of more than 15 miles to the south-west.

Analyses of samples of water from each borehole are given on Plate XII. All the samples except two are similar and appear to have been derived from a common, or similar, source. The two exceptions (from B.H. 39/53 and B.H. 4/54) contain twice as much sodium chloride as the other samples and may, in part, have been derived from a different source.

XIV. Water Reserves at Makutopora Depression

Nine boreholes were sunk and given pumping tests and two holes were sunk to obtain geological information during the present investigation. Previously, two boreholes had been sunk and partially tested. The static water level was measured in all the boreholes

M THE MAKUTOPORA DEPRESSION

.nalyses by the Geological Survey Department, Dodoma.

Plate XII

30A/53	32/53	35/53	39/53	43/53	44/53	4/54	8/54
Dec. 1953	Oct. 1953	Oct. 1953	Nov. 1953	Jan. 1954	Dec. 1953	Feb. 1954	March 1954
636	656	570	1070	590	623	943	606
85	114	125	288	91	93	266	115
82	101	117	228	91	101	116	114
279	–	84	494	174	182	78	176
161	–	154	161	140	140	268	165
235	606	218	145	232	223	396	181
–	–	–	–	–	–	–	–
3.5	3.5	2	5.9	3.3	4.6	2.4	2.2
58	–	54	36	57	55	98	45
26.5	–	25	26	23	23	44	27
52	69	78	175	55	60	161	70
46	57	66	129	51	57	65	64
1.6	1.6	0.9	2.7	1.1	2.1	1.1	1.0
683	606	485	800	555	555	769	534
–	–	–	8	8	8	8	8
D. OKENO	D. OKENO	D. OKENO	D. OKENO	D. OKENO	D. OKENO	D. OKENO	D. OKENO

IY REPORT BY ALLAN P. FAWLEY

Geological Survey Department, Dodoma 1954.

ANALYSES OF WATER FROM TH[illegible]

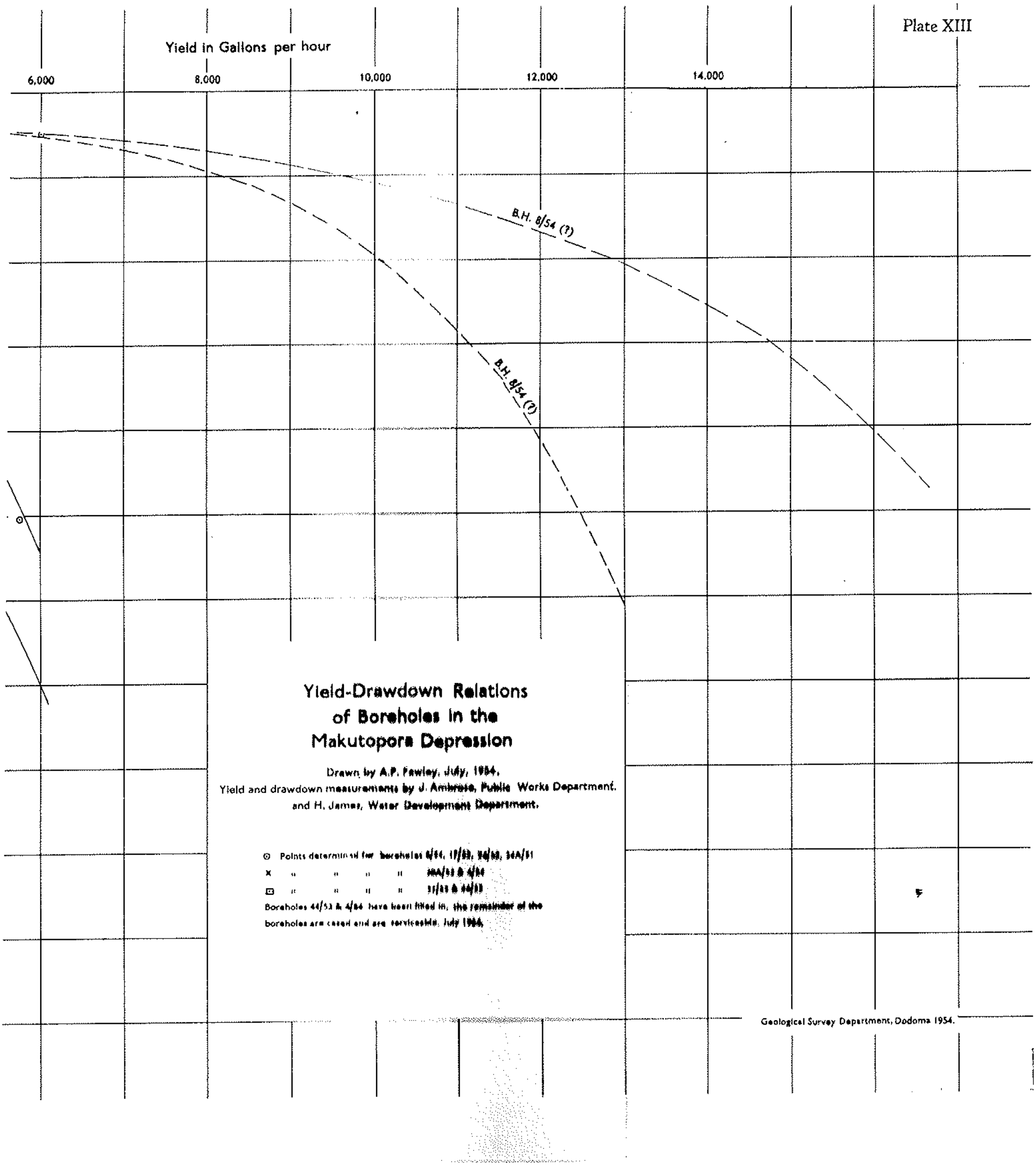
Amounts Shown in Parts Per Million   Analyses by [illegible]

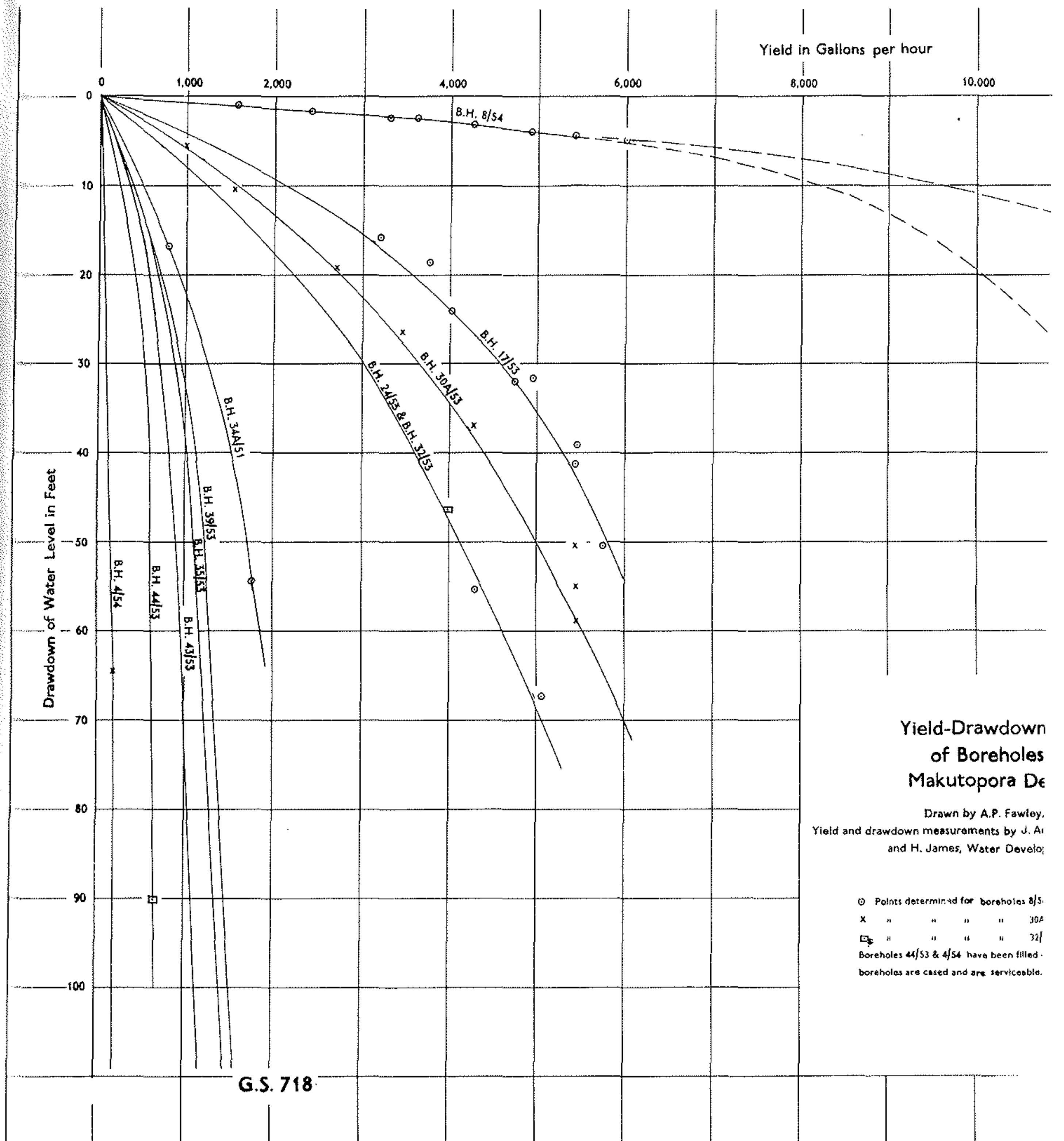
BORE HOLE No.		12/48	34A/51	17/53	17/53	24/53	30A/[illegible]
DATE SAMPLED		Aug. 1953	Jan. 1952	May 1953	Sept. 1953	Aug. 1953	Dec. [illegible]
TOTAL SOLIDS (dried at 180° C)		692	582	756	576	636	636
Approximate Composition	NaCl	148	89	129	121	114	85
	Na_2SO_4	99	165	145	116	115	87
	$NaHCO_3$	–	119	221	–	–	229
	$Mg(HCO_3)_2$	–	186	186	–	–	161
	$Ca(HCO_3)_2$	640	81	243	507	566	235
	SiO_2	–	24	56	–	–	
	NaF	3.5	–	–	2.4	3.3	5.5
Ca		–	–	60	–	–	58
Mg		–	–	31	–	–	26.5
Cl		90	–	78	74	69	57
SO_3		52	–	82	65	65	46
F		1.6	–	–	1.1	1.5	1.6
TOTAL ALKALINITY AS $Ca(HCO_3)_2$		640	402	662	507	566	683
APPROXIMATE pH		–	–	–	–	–	
ANALYST		R.A. SUTTON	R.A. SUTTON	J.SAILENI	D. OKENO	R.A. SUTTON	[illegible]

G.S. 703

TO ACCOMPANY [illegible]

Plate XIII


Yield in Gallons per hour
6,000
8,000
10,000
12,000
14,000
B.H. 8/54 (?)
B.H. 8/54 (?)
Yield-Drawdown Relations of Boreholes in the Makutopora Depression
Drawn by A.P. Fawley, July, 1954.
Yield and drawdown measurements by J. Ambrose, Public Works Department.
and H. James, Water Development Department.
Points determined for boreholes
Boreholes 44/53 & 4/54 have been filled in, the remainder of the boreholes are cased and are serviceable, July 1954.
Geological Survey Department, Dodoma 1954.



Yield in Gallons per hour
0
1,000
2,000
4,000
6,000
8,000
10,000
Drawdown of Water Level in Feet
0
10
20
30
40
50
60
70
80
90
100
B.H. 8/54
B.H. 17/53
B.H. 30A/53
B.H. 24/53 & B.H. 32/53
B.H. 34A/51
B.H. 39/53
B.H. 35/53
B.H. 4/54
B.H. 44/53
B.H. 43/53
Yield-Drawdown
of Boreholes
Makutopora De
Drawn by A.P. Fawley,
Yield and drawdown measurements by J. A
and H. James, Water Develo
Points determined for boreholes 8/5
" " " " 30A
" " " " 32/
Boreholes 44/53 & 4/54 have been filled
boreholes are cased and are serviceable.
G.S. 718

completion of drilling, and the level has been measured periodically since then in all the boreholes in which casing has been left. The information from these boreholes shows that (i) a large volume of water can be obtained from the Makutopora Depression; and (ii) that underground water is continuously flowing towards the north-east.

The maximum amount of water that can be obtained from the depression cannot be determined at present, but minimum continuous safe yield of 400,000 gallons per day seems assured. Indications are strong that far more than this could be obtained.

Sub-surface waters flow out of the depression area to the north-east. It is possible that, if the static water level were lowered during pumping by 10-20 feet near the centre of the depression, the flow of water to the north-east might be reversed and water might then flow to this centre section not only from the south-east but from the north-east as well. If so, the amount of water that could be safely drawn from the depression would be greatly increased.

XV. Observation Boreholes (Wells)

Several of the boreholes that have been cased are unlikely to be used for the Dodoma water supply, but it is strongly recommended that these boreholes be maintained in good condition as "observation wells" so that changes in the static water level during pumping from other boreholes can be noted and measured. This, along with the pumping records of the producing boreholes, will make it possible (i) to maintain a current inventory of the available water supplies; and (ii) predict the amount of water that will be available in the future.

XVI. Artificial Recharge

The run-off water that floods much of the depression during heavy rains could be recharged into the underground strata by drilling boreholes in low spots within the depression and allowing the run-off water to flow into the boreholes. As there would be a head of about 78 feet (from surface to static level), the flow of water down individual boreholes would be at the rate of several thousand gallons per hour provided the flood waters were free from excessive clay and silt.

XVII. Reservoir site on Kitunda Hill

Kitunda Hill lies two and a half miles to the south of the centre of the Makutopora Depression and rises almost 450 feet above the level of the *mbuga* surface. The top of the hill is 252 feet higher than the railway line at Dodoma.

The top of Kitunda Hill is fairly flat and is about 90 feet long by 45 feet wide. It consists of an unweathered block of granite with nearly vertical sides. The block is divided into two sections by an open fissure. Two tanks could be built, one on the east side of the fissure to hold 11,000 gallons per foot of depth, and one on the west side to hold 3,000 gallons per foot of depth. (A tank should not be constructed across the fissure as there may be some movement along it). If tanks, 20 feet deep, were built on both sides of the fissure, to hold a total of 280,000 gallons, they would increase the weight of the exposed section of the bare granite block topping Kitunda Hill by a maximum of only 5 per cent.

Tanks built on top of Kitunda Hill should be quite safe so long as precautions are taken to prevent soil erosion around the base of the large granite block. Drains, to carry away rain-water and any leakage from the tanks, should be constructed.

XVIII. Notes on Boreholes and Pumping

(i) *Spacing*.—Continuous pumping at a rate of 6,000 g.p.h. for a period of seven days from B.H. 8/54 had no effect on the static water level in B.H. 12/48 located 605 feet away. Hence, even though there may be slight interference after prolonged pumping, a spacing of 500 feet between the boreholes appears ample. Further tests may prove that a distance of 100 to 250 feet is all that is necessary but, although a second borehole within 100 feet of the large capacity borehole B.H. 8/54 would have several advantages (e.g. as an auxiliary supply), a minimum spacing of 500 feet is recommended for the next few years.

(ii) *Locations.*—The two boreholes B.H. 8/54 and B.H. 17/53, in conjunction with Dodoma's dams, will probably supply sufficient water to satisfy Dodoma's needs for the next few years. When a larger supply is needed, it is recommended that further boreholes be sunk at intervals of 500 feet along the line of boreholes B.H. 8/54 and B.H. 17/53. These holes along this line would intersect the sub-surface water flowing out of the depression at approximately, right angles to the line of flow.

(iii) *Diameter.*—The present boreholes are 8 inches in diameter. If their diameter was increased to 24 inches, their capacity would only be increased by 18 per cent. Also, there is no need to increase the diameter of the boreholes to obtain the desired yield (a 6 inch Deming turbine pump will yield up to 16,000 gallons per hour). Hence 8-inch diameter boreholes are as wide as required.

(iv) *Depth.*—The boreholes, B.H. 8/54 and B.H. 17/53, which are proposed for the original supply, have been drilled to hard bed-rock. It is recommended that all future boreholes be bored to hard bed-rock, partly to obtain a maximum yield and partly to decrease the amount of sand entering the borehole during pumping.

(v) *Borehole (Well) development.*—The process of removing silt and sand from outside the borehole casing, by drawing the silt and sand into the borehole and then bringing it to the surface, is known as "developing the well". This is done to increase the capacity of the borehole and to remove quickly a large amount of the sand and silt that would otherwise enter the borehole during routine pumping operations. Boreholes can be developed by several methods; one method, "surging", was used on B.H. 44/53 and increased the yield by about 40 per cent (i.e. from about 500 g.p.h. to 700 g.p.h.). In some parts of the world the yield of a borehole can be doubled or trebled by proper development. Some method of borehole development should be tried on all future Makutopora boreholes.

(vi) *Casing perforations.*—The casing for boreholes at the Makutopora Depression should be perforated from the horizon where water is first struck to the bottom of the borehole; in particular boreholes located near B.H. 8/54 should be perforated for a length of about 130 feet. The length of perforated casing necessary can be estimated from the cross-section drawing shown on Plate VIII.

(vii) *Depth of pump and drawdown.*—A suitable depth to place the borehole pumps would be 120 feet below the *mbuga* surface (i.e. about 40 feet below the static level). A drawdown of not more than 30 feet is recommended which, even if the holes are pumped continuously, should give a safe yield. Less wear on the pumps will be caused by sand and silt if the pump is at a depth of 120 feet rather than nearer the bottom of the borehole and, of course, more economical pumping costs can be obtained by pumping with a lift of 110 feet rather than by pumping from a greater depth. The higher the pump can be placed in the hole and still give the required yield, the better.

XIX. Recommendations and Conclusions

By pumping from a depth of 110 feet below the surface (causing a drawdown of about 30 feet) B.H. 17/53 will yield 4,600 g.p.h.; B.H. 24/53 will yield 3,100 g.p.h.; and B.H. 8/54 will probably yield a minimum of 11,000 g.p.h. This gives a total yield of 18,700 g.p.h. from the three boreholes. On continuous and prolonged pumping the yield from this depth may drop somewhat, but no drastic reduction is expected. To be cautious, however, the pumps should be installed at a depth of 120 feet below the surface. (If the pumps are installed at a greater depth they will be subjected to more wear from silt and sand.)

When a greater volume of water is needed, additional boreholes should be sunk at intervals of 500 feet along the line between B.H. 8/54 and B.H. 17/53. The boreholes should be 8 inches in diameter and deep enough to penetrate to hard granite or gneiss (see Plate VIII).

Measurements of the static water level prove that the sub-surface water flows towards the north-east and is replenished annually.

8.—EVAPORATION RATE AT DODOMA, TANGANYIKA

By ALLAN P. FAWLEY, *Mining Geologist*

CONTENTS

ABSTRACT

The rate of evaporation from a 4-foot diameter pan, air and water temperatures, humidity and dew-point, wind velocity, and rainfall are given for the period August, 1953, to December, 1954.

The rate of evaporation from reservoirs in the Dodoma area is estimated at 73 inches per year.

I. INTRODUCTION

The evaporation rate at Dodoma has been considered to be very high ever since 1930. In that year, the average evaporation and seepage loss from a reservoir built near Dodoma was found to be 0·46 inches per day, and most of this loss was assumed to be due to evaporation.

The following evaporation experiment was started in an attempt to determine the proportion of the reservoir losses that are due to evaporation.

Due to frequent changes in the African Staff who took the readings, some errors were undoubtedly made in individual readings; the average figures, however, given on the following pages, are believed to be correct to within 5 per cent.

II. APPARATUS

A 4-foot diameter pan, 8 inches deep, was set up on a flat part of the Geological Museum roof by Mr. W. Brown, (Mechanical Inspector). The flat part of the roof is 14 feet above ground level, and is surrounded by a parapet 3 feet high; the pan is half a foot higher than the top of the parapet. The pan is periodically painted aluminium on the inside and sides; the bottom is not painted.

Air and water temperatures are taken with ordinary thermometers, and a minimum-maximum thermometer is installed in the shade below the pan.

A wind gauge, which reads miles of wind instead of velocity, and a rain gauge, are installed beside the evaporation pan. The wind gauge is four feet higher than the top of the parapet.

The only hygrometer available in 1953 was a home-made one and, although considerable care was taken with the readings, they have been found to be somewhat unreliable when compared with those of a new hygrometer obtained in December, 1953. Although they are known to be only approximately correct, the humidity and dew-point figures for 1953, obtained by calculations from readings on the home-made hygrometer, are given below., The readings for 1954 were obtained from a standard hygrometer.

III. METEOROLOGICAL RESULTS

The evaporation and other results obtained for the period August, 1953, to December 1954, are shown in Table I.

TABLE I

	Air temperature (average)		Water temperature (average)	Amount of cloud between 4 a.m. & 4 p.m.	Wind velocity (average)	Rainfall	Humidity (average)			Dew point at 8 a.m.	Evaporation rate: (A) From 4-ft. diameter pan	Evaporation rate: (B) Estimated average from large reservoir*	
	°F		°F		m.p.h.	ins.	%				ins. per day	ins. per day	ins. per month
	Max.	Min.	Max.				8 a.m.	Noon	4 p.m.				
1953													
Aug. 10-31st.	85	58	80	2/10	—	Nil	—	—	—	—	0·29	—	—
Sept.	87	60	83	3/10	4·5	Nil	—	—	—	—	0·31	—	—
Oct.	89	62	88	3/10	5·6	Nil	73	47	35	59	0·37	—	—
Nov.	94	65	90	3/10	6·0	Nil	71	40	37	64	0·42	—	—
Dec. 1-15th.	97	68	95	3/10	5·6	0·15	70	47	39	65	0·40	—	—
Dec. 16-31st.	92	66	89	8/10	2·1	6·79	87	71	59	63	0·22	—	—
1954													
Jan.	89	65	89	6/10	1·4	2·20	86	68	71	65	0·20	0·14	4·34
Feb.	92	66	94	6/10	3·3	1·33	81	51	41	64	0·27	0·19	5·32
Mar.	91	66	94	5/10	3·8	2·51	86	49	38	65	0·29	0·20	6·20
Apr.	89	64	89	6/10	3·4	1·50	79	51	44	63	0·25	0·18	5·40
May.	87	61	88	5/10	3·9	0·07	80	46	37	60	0·24	0·17	5·27
June	85	57	87	3/10	3·5	Nil	72	42	33	54	0·24	0·17	5·10
July	83	56	85	2/10	3·9	Nil	78	42	33	54	0·25	0·18	5·58
Aug.	83	58	85	4/10	4·9	Nil	81	42	34	56	0·28	0·20	6·20
Sept.	86	59	88	3/10	5·8	Nil	75	41	33	56	0·32	0·22	6·60
Oct.	88	62	91	3/10	6·0	Nil	68	37	30	58	0·38	0·27	8·37
Nov.	94	65	91	3/10	6·6	Nil	77	45	42	63	0·39	0·27	8·10
Dec.	95	66	95	3/10	3·8	4·26	78	58	52	64	0·29	0·20	6·20
						11·87							72·68

*Obtained by applying a reduction factor of 0·7 to the results in column (A).

IV. Wind Velocity

The wind blows at a remarkably steady rate from the east during the dry season, generally at an average of four to six miles per hour. During the wet season the wind is more variable in direction and velocity. During both the dry and wet seasons there are a few strong gusts, but the average velocity during two-hour periods is seldom more than ten miles per hour.

V. Evaporation Rate from Reservoirs

Experiments have shown that water evaporates from a small pan at a faster rate than from a larger body of water; also if the pan is installed on land, water evaporates from it at a faster rate than if the pan is floating in water. Kempe (1953)[1] gave evidence which indicates that the ratio of pan evaporation to that of open reservoirs is between 0·6 and 0·8 (i.e. to obtain the evaporation rate in a reservoir, the evaporation rate in a pan must be reduced by multiplying it by from 0·6 to 0·8).

The pan on the roof of the Geological Museum is somewhat sheltered from the wind and the wind velocity on the roof is probably less than at either of the reservoirs, but the maximum water temperature in the pan becomes considerably greater than in the reservoir. An example of the difference in water temperature of the pan and of the surface reservoir water at Msalatu Reservoir for September 16th, 1953, follows:—

Time	8·30 a.m.		Noon		4·00 p.m.	
	Air	Water	Air	Water	Air	Water
Roof pan	67° F	65° F	77° F	72° F	86° F	86° F
Reservoir	68	68	81	70	91	76

The rate of evaporation from the Dodoma reservoirs, obtained by applying a reduction factor of 0·7 to the results obtained from the evaporation pan for 1954, range from 4·34 to 8·37 inches per month and total 73 inches for the entire year.

[1] Kempe's Engineer's Year Book for 1953, Morgan Brothers, London—p.802.