Land classification	Soil mechanical classification	D_{10}	Uc	U'c
Lower terraces	S	0.11-0.23	2.9-8.3	0.8-1.0
Alluvial fans	S or S-F	0.075-0.15	2.9-6.2	0.8-1.3
Flood plains	F	-	-	-

Remarks D_{10}; Effective grain size
Uc ; coefficient of uniformity
U'c; coefficient of curvature

More details about the above figures are shown in Table B-1. According to this, the lower terraces consist of sand (S) in texture, and are made from well-graded soils. The alluvial fans consist of sand (S) and/or sandy soils (S-F) in texture, and their grain size distribution is comparatively similar to that of the lower terraces.

From the gradation analysis at the field it was difficult to clarify the detailed mechanical condition for the flood plains locatd mainly on the lower land of each scheme area.

However, from the result of test-pitting, it was confirmed that this land consists of a homogeneous layer containing silt of a dark gray color. The liquid limit of this soil is low and cracks are easily caused when the soil is dry.

4.2.2 Bearing Capacity and Permeability of Foundation

(1) N-value

An investigation of the bearing capacity was conducted in order to grasp the foundation condition for the main canals and the major structures, and then to obtain the engineering criteria for the foundation treatment etc.

The investigation includes the check of soils in each scheme area by auger boring along the routes of the irrigation system, and by soil sounding tests for the sites of the major structures.

The soil sounding test was conducted using a cone penetrometer and the N-value was measured at a depth ranging from 1.5 to 2 meters. The following shows the range of N-value in the land of each scheme area:

Scheme	N-value
Kisiwani	4-9
Gonja	2-6
Ndungu	10-13
Kihurio	3-29
Igoma	15

According to the results of the investigation, the N-value of the lands in each scheme area is described as follows;

(a) Kisiwani scheme area

Most of the routes of the main canals are located in the land of the alluvial fans, excluding a small downstream portion which traverses through the flood plains. The N-value of the soils of these lands ranges from 4 to 6. The land along the route of the floodway, which is planned as the river trainning work at the downstream of the existing weir on the Nakombo river, consists of soils which are sandy in texture and whose N-value ranges from 6 to 9.

(b) Gonja scheme area

In this scheme area, the land of the flood plains is developed widely from the Same-Tanga road along the Hingilili river, and the land of the alluvial fans is developed to along the Same-Tanga road located in the south side of that river. The proposed main canals run mainly in the flood plains in their upper reaches , and then after crossing the Hingilili river, they run in the alluvial fans.

The proposed route of the floodway is located in the flood plains. The N-value of the lands in this scheme area is generally low, compared with those in other scheme areas.

In particular the N-values of the proposed sites for major structure near the Same-Tanga road are low (about 2). Among the routes of the main canal, the one crossing the Hingilili river consists of sandy soils in texture and which has a N-value of 6.

(c) Ndungu scheme area

The proposed routes of the main canals are located in the lower terraces and the alluvial fans. These lands are suitable for the structures, with the N-values more than 10. The land along the floodway running in the alluvial fans includes comparatively clayey soils.

(d) Kihurio scheme area

The routes of main canals are located in the higher terraces or in the lower terraces and the alluvial fans. The floodway runs in the land of the alluvial fans. The soil condition of this land is generally good, showing a higher N-value than the other scheme areas. For the lower terraces, the N-value ranges from 8 to 20.

(e) Igoma scheme area

The land of this scheme area consists mainly of flood plains, with the surrounding land consisting of lower terraces. The routes of main canals are located in lower terraces which show relatively high N-value.

The N-value of the intake site proposed at the Kambaga river shows 15.

(2) Bearing Capacity

Bearing capacity of the soils can be estimated from the N-value measured by cone penetration test, by applying the Terzaghi's method. The allowable bearing capacity of the soils along the main canals and major structures is tabulated as below;

scheme	angle of shearing resistance (°)	Allowable bearing capacity (t/m^2)	
		Long term capacity	Short term capacity
Kisiwani	28 - 30	10 - 15	11 - 17
Gonja	28 - 29	10 - 12	11 - 13
Ndungu	30 - 31	15 - 16	17 - 18
Kihurio	28 - 36	10 - 40	11 - 46
Igoma	32	18	20

The above table was made by disregarding the cohesion of the soil, since the soil properties of the lands consist of sandy soils, as mentioned above. The detail of each site is shown in Table B-3. From this result, the engineering property of soils for construction of the main canals and major structures is discussed as follows;

(a) The allowable critical height of the canal embankment is estimated at about 5 meters. However, from the viewpoint of the layout of the irrigation system, the embankment height is suggested to be lower than 2 meters. Therefore, the bearing capacity of the soils can be sufficient for such embankment works.

(b) As for the foundation of the related structures such as siphon, culvert, and turnont etc., it is preferable to use shallow foundations such as footing foundations.

(3) Permeability

The permeability of soils was checked by a permeability test in compliance with the criteria of the U.S. Bureau of Reclamation. According to the result tested, the permeability coefficient does not vary from place to place, and shows 10^{-4}cm/sec in average. However, the permeability coefficient of the soil along major rivers is comparatively high, showing 10^{-3}cm/sec. The range of the permeability coefficients for each scheme area is shown below;

Description	Permeability coefficient (cm/sec)
Kisiwani scheme	$1.5x10^{-4}$
Gonja scheme	-
Nohungu scheme	$1.2 - 4.3x10^{-4}$
Kihurio scheme	$0.8 - 6.3x10^{-4}$
Igoma scheme	$2.4 - 4.0x10^{-4}$
Nakombo river	$4.5x10^{-3}$
Hingilili river	$1.4x10^{-3}$
Yongoma river	$1.1x10^{-3}$

Details are shown in Table B-1.

4.3 Embankment Materials

4.3.1 Sample soils

In order to clarify the soil mechanical characteristics as the embankment materials, a total of 8 representative samples were sent to Japan, and laboratory tests werecarried out in detail. The results of the tests are shown in Table B-2. From the table, it is evident that most of the sample soils are classified into the sandy soils in texture. Their mechanical characteristics are explained below;

(a) The soil specific gravity ranges from 2.7 to 2.8

(b) The liquid limit (L.L) ranges from 27% to 30% except for the sample soil (Kisiwani) obtained near the Nakombo river. This sample soil shows 46% of the liquid limit. Plastic limit (P.L) ranges from 16% to 19% in all of the samples.

(c) The plasticity index (P.I) varies from place to place. Especially, the sample soil (Igoma(1)) obtained from the proposed dam site shows non-plastic nature.

(d) The natural moisture content also varies from place to place.

4.3.2 Soil Mechanical Characteristics

(1) Result of the laboratory test

In order to clarify the engineering criteria for construction, analysis was performed in detail for the following three sample soils, obtained from the land of the lower terraces which is considered to be suitable as an embankment material.

(a) Igoma (1), obtained from the downstream area of the proposed Igoma dam site,

(b) Igoma (2), obtained from the proposed reservoir area of the Igoma dam, and

(c) Kalimawe, obtained from the existing Kalimawe dam site. From the results of these detail tests, soil mechanical and engineering characteristics are discussed below;

(d) Compaction characteristics:

The compaction tests carried out based on the standard completion method, show different curves as shown in Fig. B-17. The maximum dry density and the optimum moisture content are summarized below.

Sample soil	Dry density (kg/cm^3)	Moisture content (%)
Kalimawe	1931	13.1
Igoma (1)	1878	13.5
Igoma (2)	1750	16.3

The dry density of the Igoma (1) soils does not greatly vary relative to the variation of the moisture content. Soil showing such characteristics is not so suitable as an embankment material. On the other hand, the moisture content to be attained is 11% at a maximum dry density of 90%. This is nearly equal to the natural moisture content of soils in the dry season.

(e) Permeability characteristics:

The permeability coefficient of the embankment materials after compaction is expected to reach around 10^{-4}/sec and 10^{-5}/sec. The relationship between permeability and compaction is illustrated in Fig. B-18.

(f) Shearing characteristics:

The shearing test shows that the cohesion and internal friction angle for soil obtained from the proposed borrow area near the Kalimawe dam are:

Cohesion	C = 3.6t/m
Angle of internal friction	$\phi = 35^o$

This result was obtained under the condition that the dry density and moisture content are 1.770 g/cm^3 and 7%, respectively.

The detail is as shown in Fig. B-19.

(g) Consolidation characteristics:

The consolidation test results are shown in Fig. B-20 and B-21. From these figures, the index for the consolidation characteristics are summarized below.

Consolidation index	$C_c = 0.180$
Maximum precompression	$P_c = 7$ t/m^2

(2) Design value and stability of slope

Based on the result of the laboratory test, the following design values are determined to be adopted;

- Wet density $r_e = 1.800$ g/cm^3
- Dry density $r_d = 1.700$ g/cm^3
- Cohesion c = 3.0 kg/m^2
- Angle of internal friction $\phi = 35^o$
- Coefficient of permeability K = 1.0x10^{-4}cm/sec

The relationship between embankment height and angle of slope for the side slope of the canal embankment, are estimated as shown below;

Embankment height (m)	Allowable maximum angle of slope
Less than 2	80 (1:0.17)
2 - 4	60 (1:0.6)
4 - 5	50 (1:0.8)

From this result, a side slope of 1:0.5 will be suitable for the stability of the slope adopted for the canal design. Decrease of the embankment height after construction can be disregarded from the results of the consolidation test.

4.3.3 Borrow area for embankment materials

According to the soil mechanical test and the reconnaissance survey for the borrow area, it is desirable that the materials for embankment be collected from the sloping lands of the lower terraces which are developed widely in the higher land in each scheme area. The materials are to be collected from the shallow layer, since the gypsite bed is generally found in layers 3 meters below the surface.

On the other hand, it desirable that the embankment works are executed by maximum use of in-site materials obtained from excavation. From the above mentioned point of view, the following is suggested for collecting the materials;

- Materials for canal embankment

The canal embankments, as a rule, should use in-site materials obtained from canal excavation. It will be generally possible since the actual height of canal embankment is generally low. Extra materials should be obtained from the land of the lower terraces if there occurs a shortage of embankment materials.

- Embankment materials for the Igoma dam.

The land of the lower terraces, developed behind the proposed Igoma dam site, is suitable as a borrow area, from the result of laboratory tests (Fig. B-22).

- Embankment materials for the Saseni dam

It is difficult to collect the materials from the land of the lower terraces, because the transport of the materials is costly. The proposed borrow area is the downstream of the dam site (Fig. B-22), according to the investigation of the dam site.

However, since the volume expected is too small, it is proposed to use the rock materials which are found abundantly in and around the dam site. The proposed type of the dam will be a rock-fill type with the central core.

- Embankment materials for Yongoma dam

The materials for the dam embankment can be collected from the sloping land of the right side, which is located in the upper stream of the dam site along the Yongoma river (Fig. B-22). The borrow area will be widened since the available depth seems to be shallow.

- Embankment materials for the Hingilili dam

The materials for the dam embankment can be collected from the sloping land left of the site of the proposed dam site (Fig. B-22).

4.4 Sand and Gravel

4.4.1 Sand Materials

In and around the project area there are sands deposited in the river beds of the major rivers and small tributaries.

Most of these sands except for those at the river bed of the Kambaga river and that of hinterlands of the Igoma scheme area, are not favourable for concrete aggregates because they are too fine.

Sands of the Kambaga river bed near the Gonja Village were originally derived from the Tossa Mountains by flood run-off. The result of electrical sounding at the river bed of Kambaga river suggests that the beds are more than 2 meters thick. Their grain size distribution shows a good graded curve for the fine aggregate of concrete, shown as in Fig. B-24. The soil mechanics indices are shown as below.

Effective grain size	0.19 m/m
Coefficient of uniformity	5.2
Coefficient of curvature	1.3

The river bed deposits of the hinterlands of the Igoma scheme, are similar to that of Kambaga river. From the result of these investigation, it is suggested that fine aggregates be collected from the Kambaga river bed and the hinterlands of the Igoma scheme area.

On the other hand, fine aggregates might be obtained from the excavated materials at the river beds of the proposed weir sites in the major river. However, the available volume is not so great since it includes considerable amount of gravels.

4.4.2 Gravel

The quarry sites are located at the sloping lands in the foothills of the Pare Mountains along the Same-Tanga road. The coarse aggregate for the concrete and the pavement materials for the proposed road can be collected from these areas. The quarry sites for each scheme are discussed below.

- Kisiwani scheme

The coarse aggregates for the concrete can be collected from the terraces of the upper stream of the proposed weir site along the Nakombo river. The weathered rocks along the Same-Tanga road are suitable for pavement materials.

- Gonja scheme

Coarse aggregate for concrete can be taken from the excavated gravels at the proposed weir site of the Hingilili river and river bed gravels around the proposed weir site. The pavement materials can be collected from the weathered rocks near the Igoma village.

- Ndungu scheme

Similar to the Gonja scheme, the coarse aggregates can be obtained from the excavated gravels at the proposed weir site of the Yongoma river. The pavement materials also can be collected from the weathered rocks along the Same-Tanga road.

- Kihurio scheme

Coarse aggregates can be obtained from the proposed weir site of the Saseni river. The pavement materials can be collected widely from the sloping lands in the foots of the Pare Mountains

- Igoma scheme

Both coarse aggregates and pavement materials can be collected from the mound of quartzose gneiss which is located on the center of this scheme area along the Same-Tanga road.

Table B-1 SUMMARY OF FIELD INVESTIGATION

Sampling Location		Classification: Geology	Classification: Soil mechanics	Sieve analysis: Percentage of weight passing through the sieve (m/m) 4.76	2.38	1.68	1.19	0.59	0.42	0.297	0.232	0.149	0.074	D10 (m/m)	Uc	U'c	Field test: Cone-penetration (N-valve)	Field test: Permiability (cm/sec)
Kisiwani	K-1	Alluvial-Fans	S	100	90		77	57		33		8	2	0.15	3.5	1.3	4	4.0×10^{-3}
	K-2	Flood-Plains															6	
	K-3	Alluvial-Fans															6	
	K-4	Flood-Plains															9	1.5×10^{-4}
	K-5	Lower-Terraces	S	100	64		50	38		23		9		0.15	8.3	1.0		
	K-6	Alluvial-Fans				100	82	46		23		7						
Igoma	I-1	Flood-Plains	S			100	88	69		37		5	1	0.17	2.9	0.8	15	4.0×10^{-4}
	I-2	Lower-Terraces																2.4×10^{-4}
Gonja	G-1	Alluvial-Fans	S			100	76	54		35		13	2	0.12	6.2	0.8	6	1.4×10^{-3}
	G-2	Flood-Plains															2	
	G-3	Alluvial-Fans	S	100	93		82	63		38		11	3	0.14	4.2	0.8	3	
	G-4	(River-Bed)	S	94	87		70	37			11	1		0.23	4.2	1.0		
	G-5	Alluvial-Fans															3	
Ndungu	N-1	Lower-Terraces	S	100	94		81	61		40		16	5	0.11	6.0	0.9	13	
	N-2	Alluvial-Fans	S-F			100	96	81		59		30	9	0.075	4.3	0.9	10	
	N-3	- do -																1.2×10^{-4}
	N-4	Lower-Terraces																4.3×10^{-4}
	N-5	- do -															12	
	N-6	Alluvial-Fans																
Kihurio	Ki-1	Lower-Terraces	S				70	47		28		10	3	0.15	5.7	0.8	8	
	Ki-2	Alluvial-Fans															3	
	Ki-3	Lower-Terraces															29	
	Ki-4	Alluvial-Fans																6.3×10^{-4}
	Ki-5	- do -	S-F				100	86		78		32		0.082	2.9	1.1	3	0.8×10^{-4}
	Ki-6	Lower-Terraces	S	100	98		91	72		42		14		0.12	3.0	1.0		
	Ki-7	(River-Bed)				100	98	95	36	12		1						

Remarks: D10; Effective grain size
Uc ; Coefficient of uniformity
U'c; Coefficient of curvature

Table B-2 (1/2) SOIL TESTS FOR EMBANKMENT MATERIALS

Soil Sample			Proposed Borrow Area		
			Kalimawe	Igoma (1)	Igoma (2)
Gradation	Gravel	%	12	23	22
	Sand	%	53	63	43
	Silt	%	28	8	21
	Clay	%	7	6	14
	Maximum grain size	mm	19.1	19.1	9.52
Consistency	Liquid limit L.L	%	26.7		37.2
	Plastic limit P.L	%	16.2		15.6
	Plasticity index P.I		10.5		21.6
Specific gravity Gs			2.769	2.802	2.629
Classification			SF	S - F	S - F
Natural condition	Moisture content	%	5.8	4.9	8.36
	Dry density	kg/cm^3	1497	1839	1582
	Wet density	kg/cm^3	1598	1973	1764
	Void ratio		0.850	0.524	0.654
	Degree of saturation	%	21.9	39.0	44.2
Compaction	Optimum water content	%	13.1	13.5	16.3
	Maximum dry density	kg/cm^3	1931	1878	1750
Consolidation	Compression index		0.18		
	Maximum pre-compression	kg/m^2	7		
Shearing strength	Cohesion C	t/m^2	3		
	Angle of internal friction	ϕ	35°3'		

Table B-2 (2/2) SOIL TESTS FOR EMBANKMENT MATERIALS

Soil Sample			Saseni	Kisiwani
Gradation	Gravel	%	0	0
	Sand	%	98	46
	Silt	%	1	31
	Clay	%	1	23
	Maximum grain size	mm	1.8	4.76
Consistency	Liquid limit L.L	%		46.4
	Plastic limit P.L	%		19.2
	Plasticity index P.I			26.9
Specific gravity Gs			2.765	2.684
Classification			S	F
Natural condition	Moisture content	%	15.3	35.2

Soil Sample			Gonja	Ndungu	Kihurio
Gradation	Gravel	%	1	0	2
	Sand	%	58	52	42
	Silt	%	19	24	32
	Clay	%	22	24	24
	Maximum grain size	mm	4.76	4.76	4.76
Consistency	Liquid limit L.L	%		33.4	38.3
	Plastic limit P.L	%		16.4	16.2
	Plasticity index P.I			17.0	22.1
Specific gravity Gs			2.773	2.746	2.766
Classification			S F	S F	F
Natural condition	Moisture content	%	10.7	15.3	13.6

Table B-3 ALLOWABLE BEARING CAPACITY (t/m^2)

Sampling Location	Soil Classification	N-value	Index					Allowable bearing Capacity (t/m^2)		Remarks
			C	ϕ	N_c	N_r	N_q	q_ℓ	q_s	
Ki - 1	S	8	-	29	14.5	5.3	11.0	12	13	
Ki - 2		3	-	28	11.4	4.4	9.1	10	11	*q_ℓ = long-term capacity
Ki - 3		29	-	36	42.2	30.5	33.6	40	46	q_s = short-term capacity
Ki - 5	S - F	3	-	28	11.4	4.4	9.1	10	11	
N - 1	S - F	13	-	31	18.0	7.4	15.0	16	18	$q_\ell = \frac{1}{3}(\alpha \cdot C \cdot N_c + \beta \cdot r_1 \cdot B \cdot N_r + r_2 \cdot D_f \cdot N_q)$
N - 2	S - F	10	-	30	17.0	6.3	14.0	15	17	
N - 5		12	-	31	18.0	7.4	15.0	16	18	$q_s = \frac{2}{3}(\alpha \cdot C \cdot N_c + \beta \cdot r_1 \cdot B \cdot N_r + \frac{1}{2} r_2 \cdot D_f \cdot N_q)$
G - 1	S	6	-	29	14.5	5.3	11.0	12	13	$\alpha = 1.3$
G - 2		2	-	28	11.4	4.4	9.1	10	11	$\beta = 0.4$
G - 3	S	3	-	28	11.4	4.4	9.1	10	11	$B = 1.0$ m
G - 5		3	-	28	11.4	4.4	9.1	10	11	$r_1 = 1.5\ t/m^3$
I - 1	S	15	-	32	20.9	10.6	16.1	18	20	$r_2 = 1.5\ t/m^3$
K - 1	S	4	-	28	11.4	4.4	9.1	10	11	$D_f = 2.0$ m
K - 2	S	6	-	29	14.5	5.3	11.0	12	13	$\phi = 0.3N + 27°$
K - 3		6	-	29	14.5	5.3	11.0	12	13	
K - 4		9	-	30	17.0	6.3	14.0	15	17	

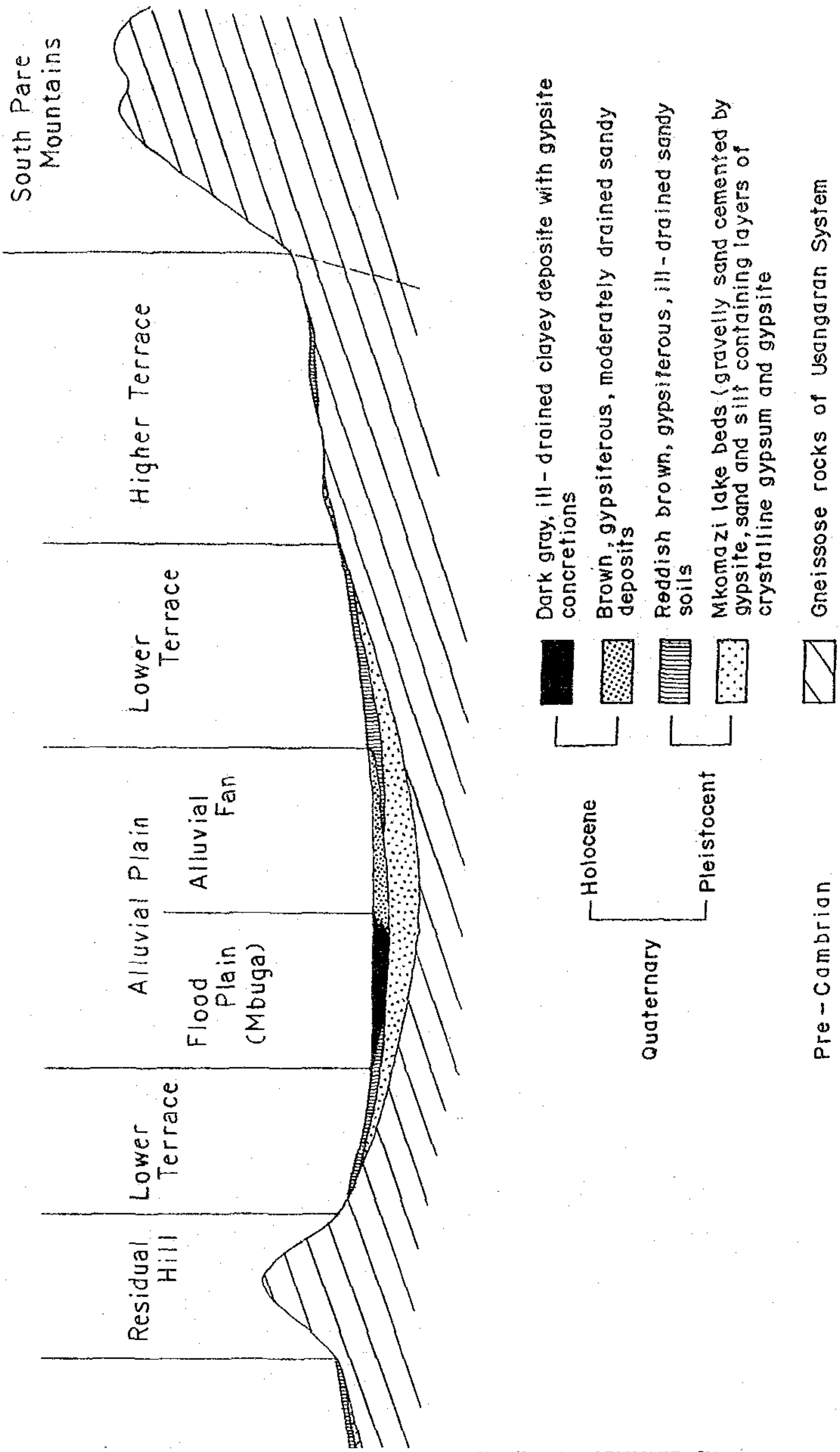


Fig. B-1 SCHEMATIC PROFILE OF GEOLOGY IN THE MKOMAZI VALLEY

Geological Age		Symbols	Topography	General Geology
Quaternary	Holocene	(blank box)	Flood Plains	Dark gray, ill-drained clayey deposits with gypsite concretions
		(horizontal lines)	Alluvial Fans	Brown, gypsiferous, moderately drained sandy deposits
	Pleistocene	(dots)	Lower Terraces	Reddish brown, gypsiferous, ill-drained sandy soils underlain by Mkomazi Lake Beds
		L L	Higher Terraces	Exposures of gneissose basement rocks, party overlain by thin reddish brown soils or gypsite beds
Pre-Combrian		~~	Mountains and Residual Hills	Gneissose basement rocks of Usangaran System

x Points of geologic columnar sections in Fig.

● Existing boreholes

○ Points of electrical sounding

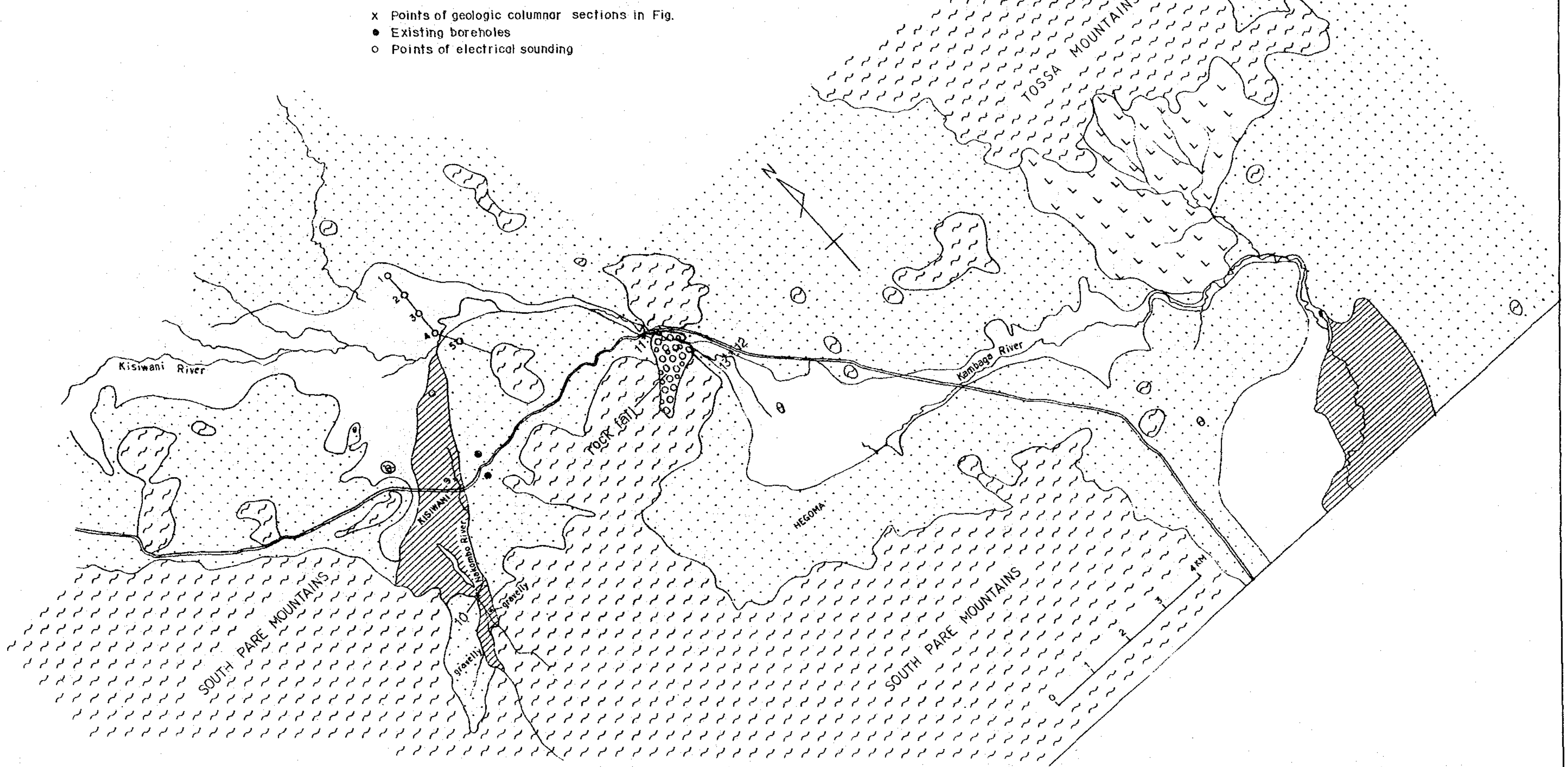


Fig. B-2 (1/2) GEOLOGICAL MAP

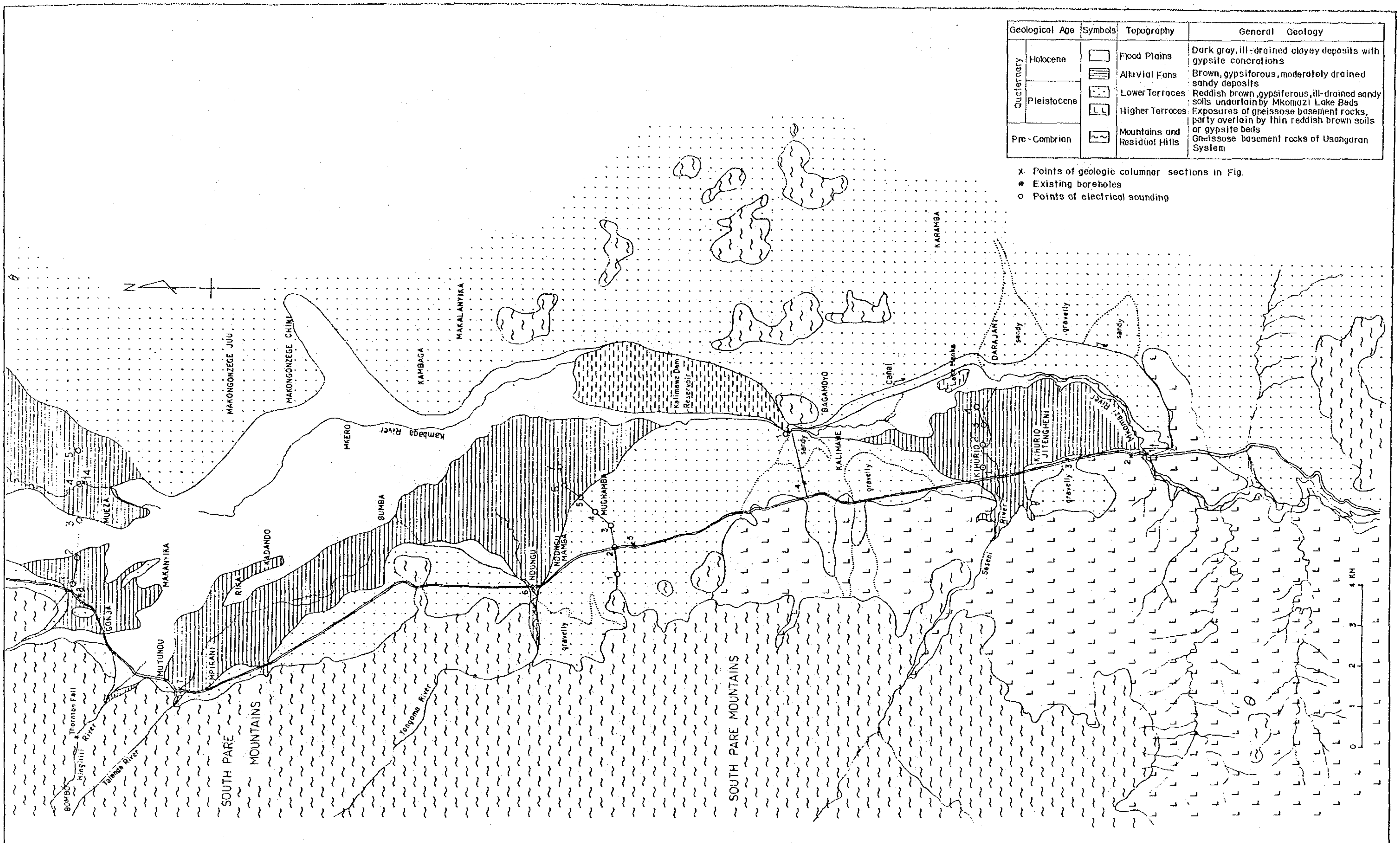
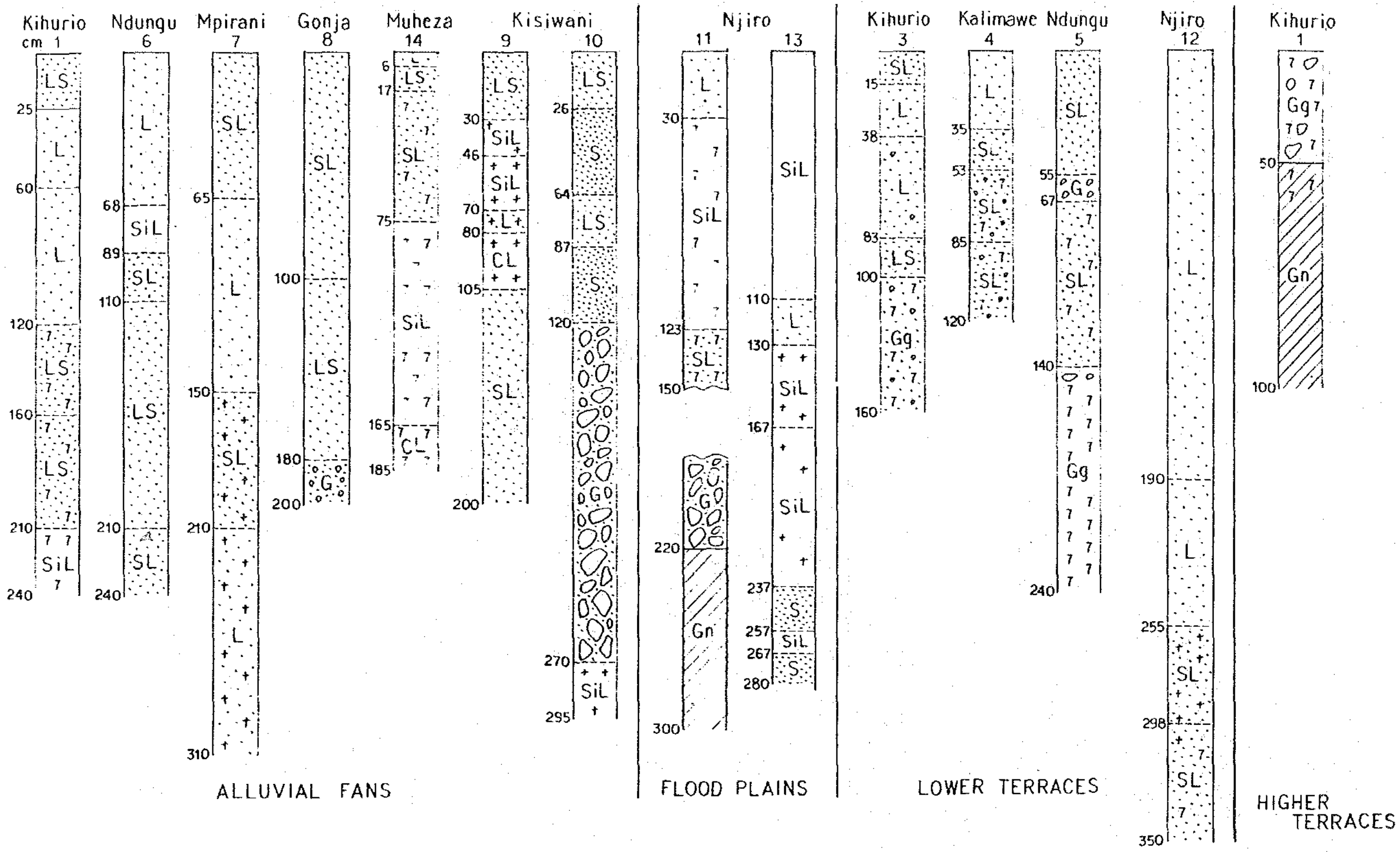


Fig. B-2 (2/2) GEOLOGICAL MAP



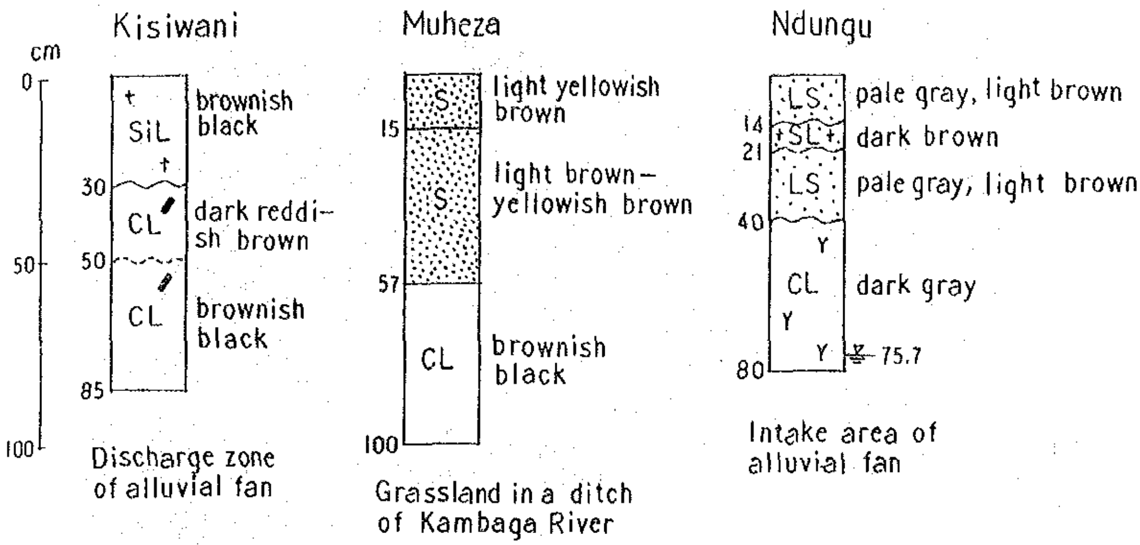
LEGEND

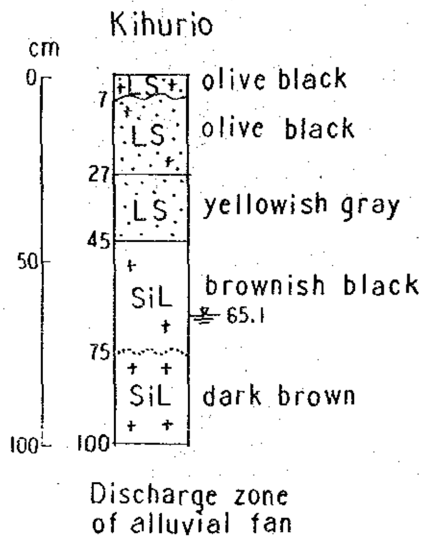
S : Sand
LS : Loamy sand
SL : Sandy loam
L : Loam
SiL : Silt loam
CL : Clay loam

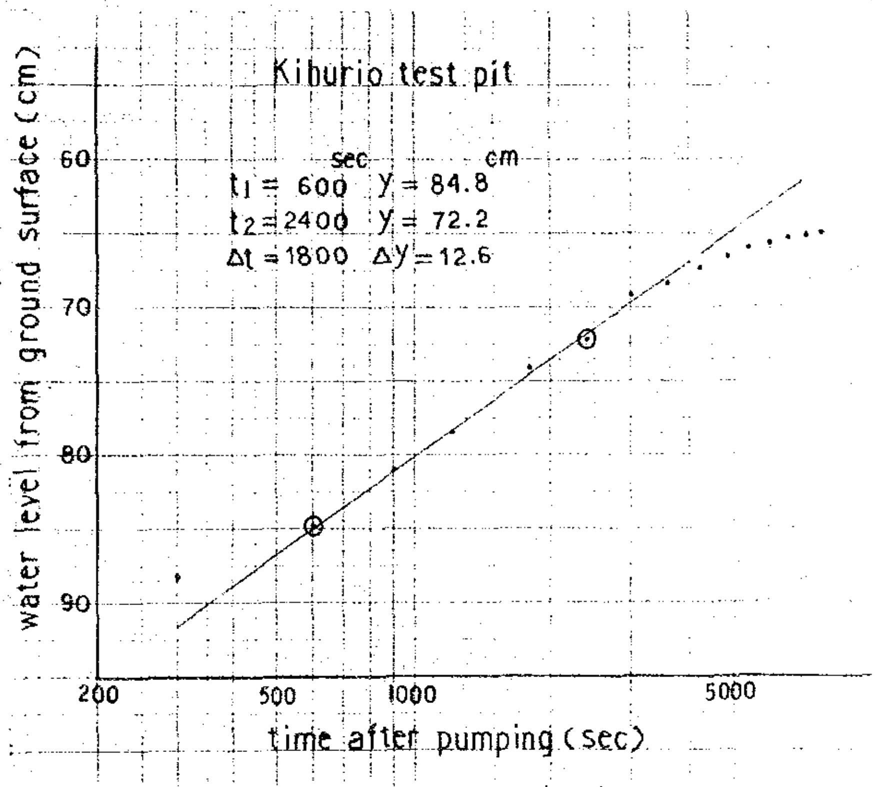
G : Gravel and sand
Gg : Gravel and sand semented by gypsite
Gn : Gneiss

+ : Reddish brown mottles
7 : Gypsum patches or gypsite concretions

Fig. B-3
GEOLOGIC COLUMNAR SECTIONS IN OUTCROPS





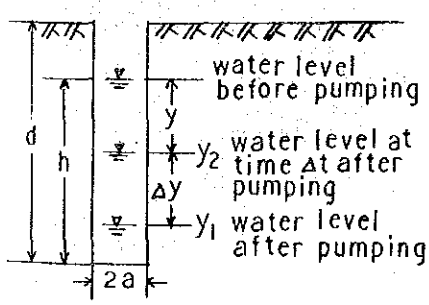


Formula of calculation

$$k = \frac{4.63}{(20 + h/d)(2 - y/h)} \cdot \frac{a}{y} \cdot \frac{\Delta y}{\Delta t}$$

k : cm/sec

others : cm or sec



Calculation of Coefficient of permeability

$$k = \frac{4.63}{(20 + 29.4/94.5)(2 - 8.9/29.4)} \cdot \frac{50}{8.9} \cdot \frac{12.6}{1800}$$

$$= 5.3 \times 10^{-3} \text{ (cm/sec)}$$

Fig. B-4 SOIL PROFILES OF TEST PITS AND RESULTS OF PERMEABILITY TEST BY RECOVERY METHOD

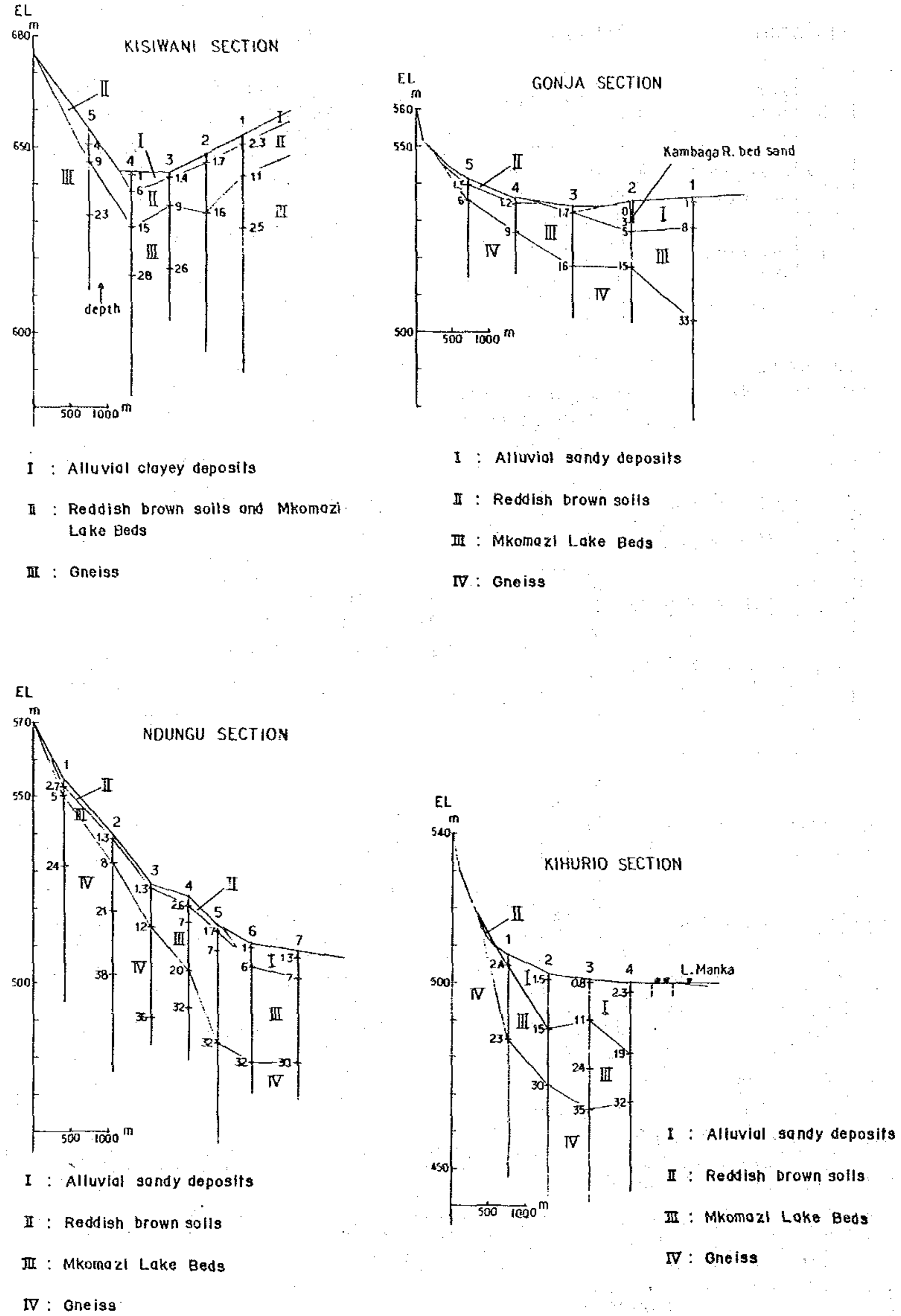


Fig. B-5 SUBSURFACE GEOLOGIC SECTION AFTER ELECTRIC SOUNDING

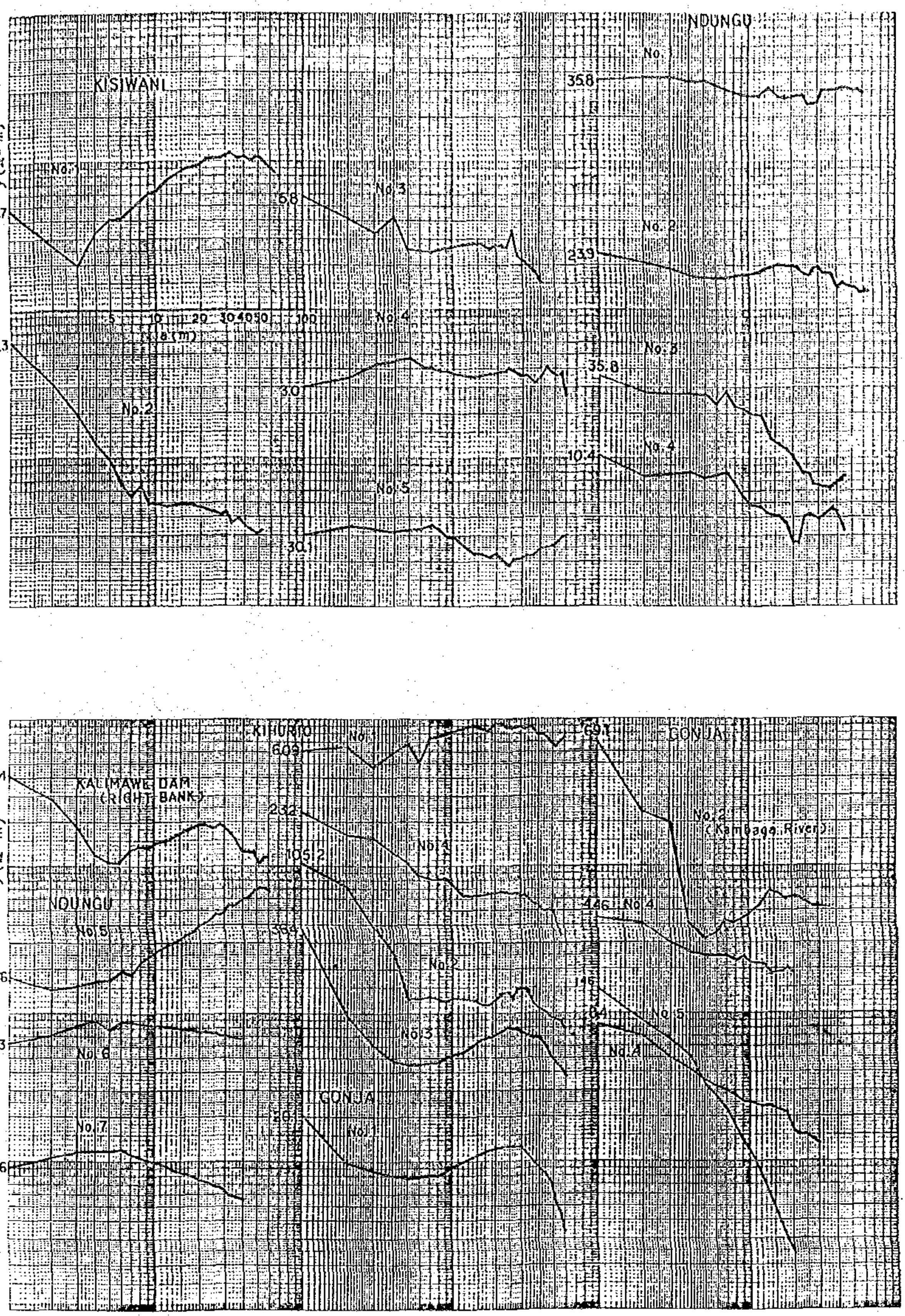


Fig. B-6 APPARENT RESISTIVITY (ρ) - DEPTH (a) CURVE BY WENNER'S ARRANGEMENT

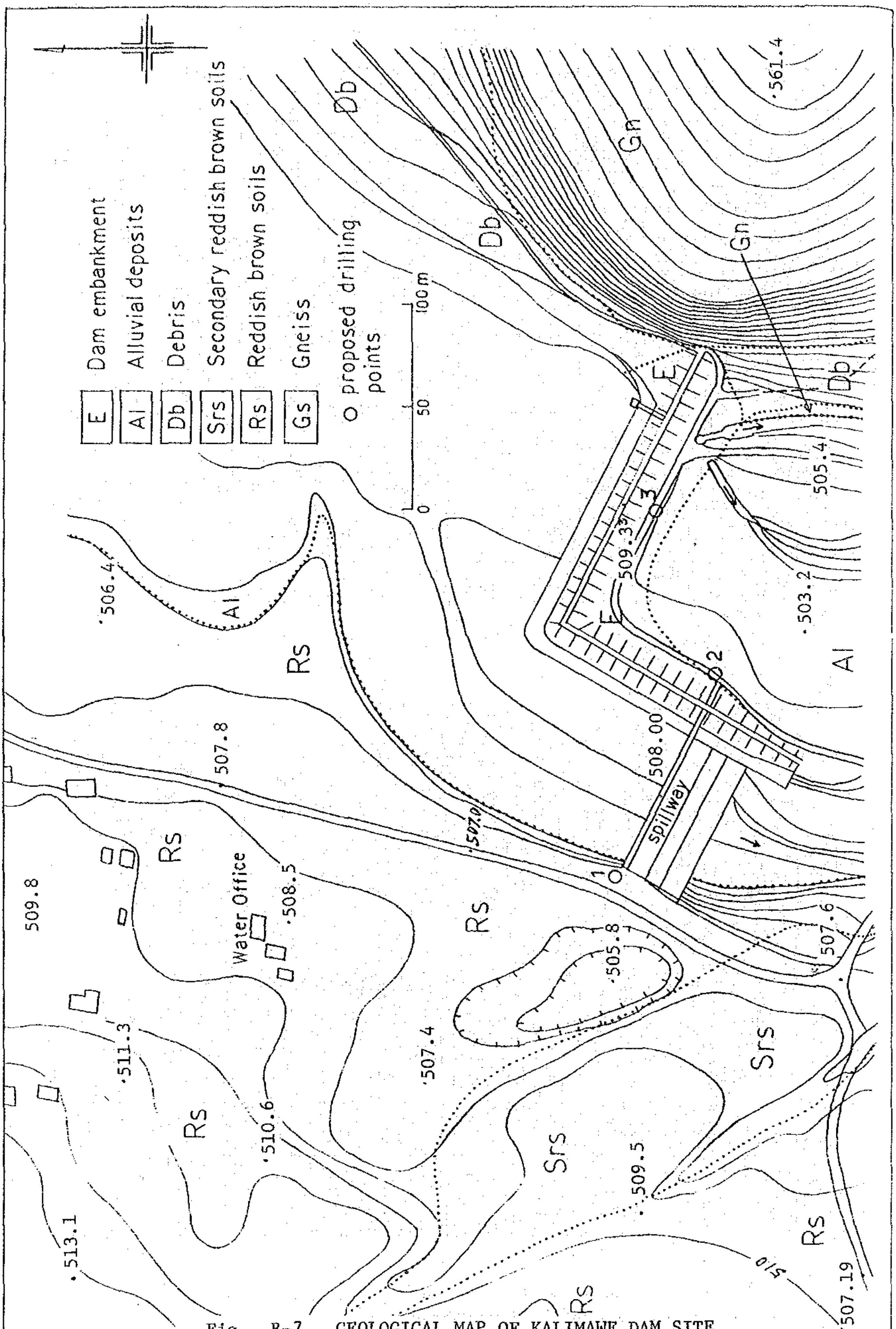


Fig. B-7 GEOLOGICAL MAP OF KALIMAWE DAM SITE

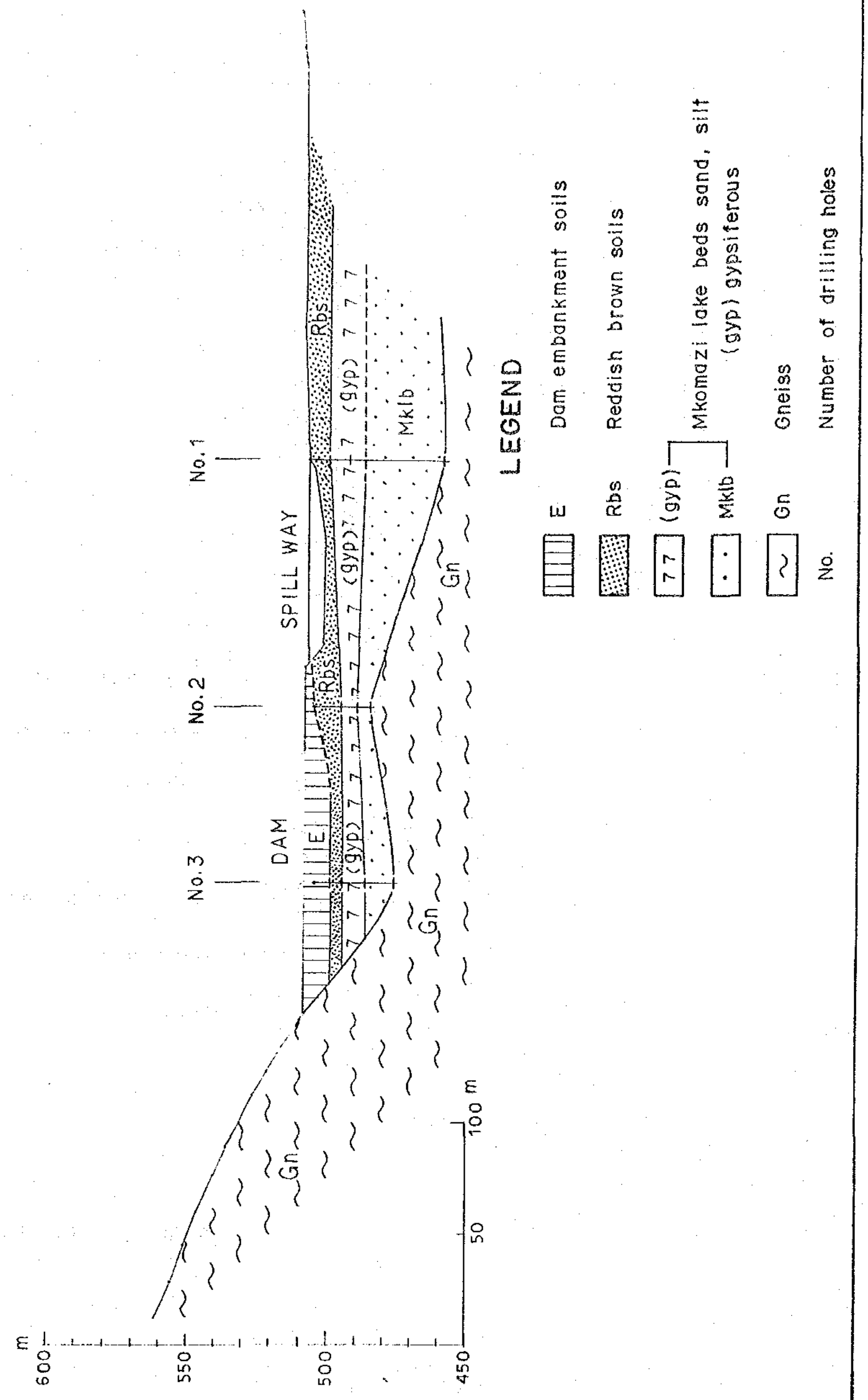


Fig. B-8 GEOLOGICAL SECTION OF KALIMAWE DAM SITE

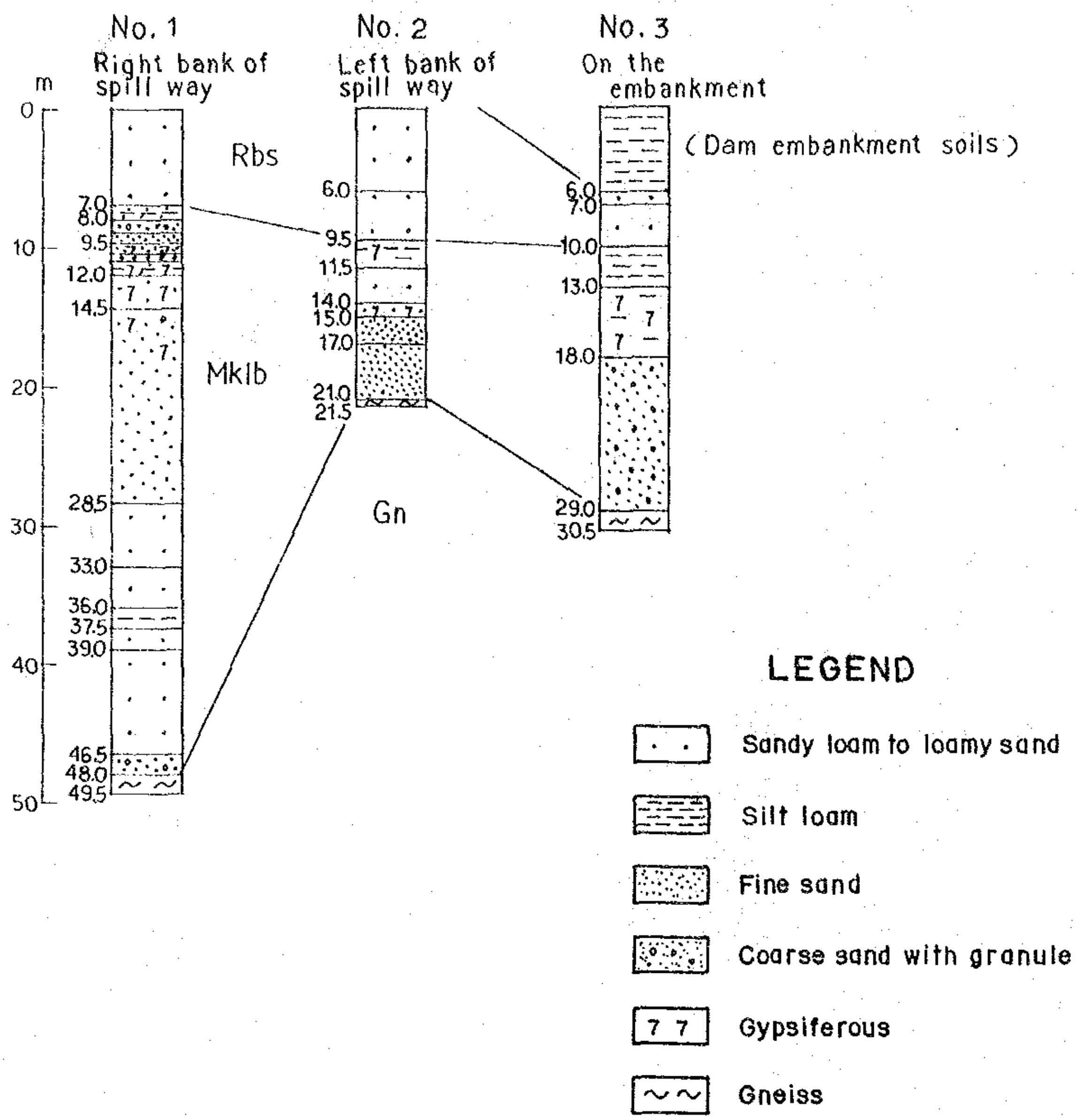


Fig. B-9 GEOLOGIC COLUMNER SECTIONS OF DRILLING HOLES AT KALIMAWE DAM SITE

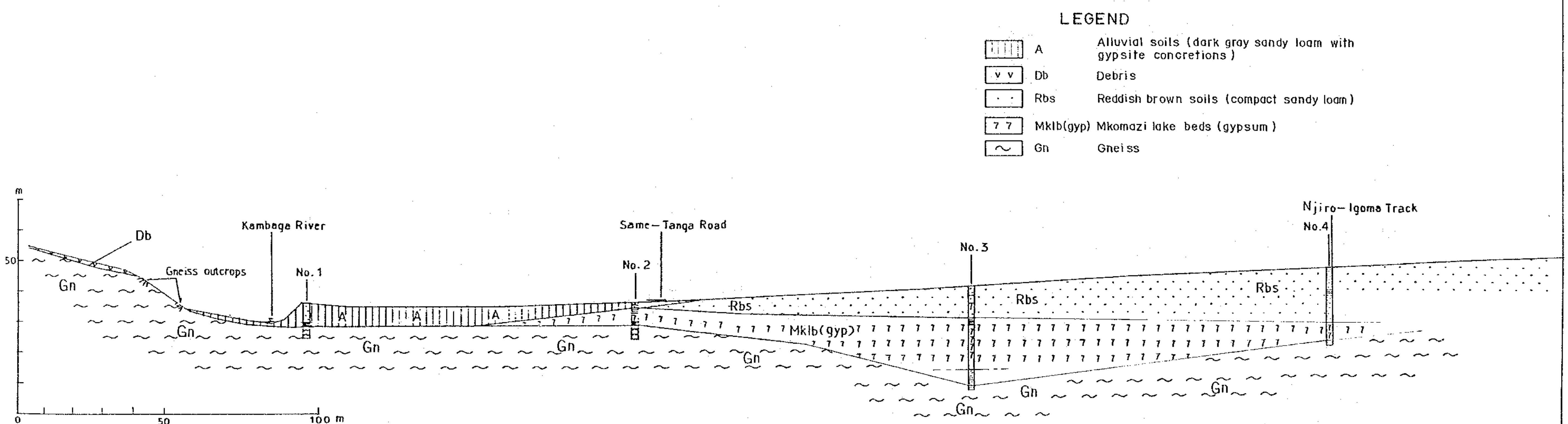


Fig. B-10 GEOLOGICAL SECTION OF PROPOSED IGOMA DAM SITE

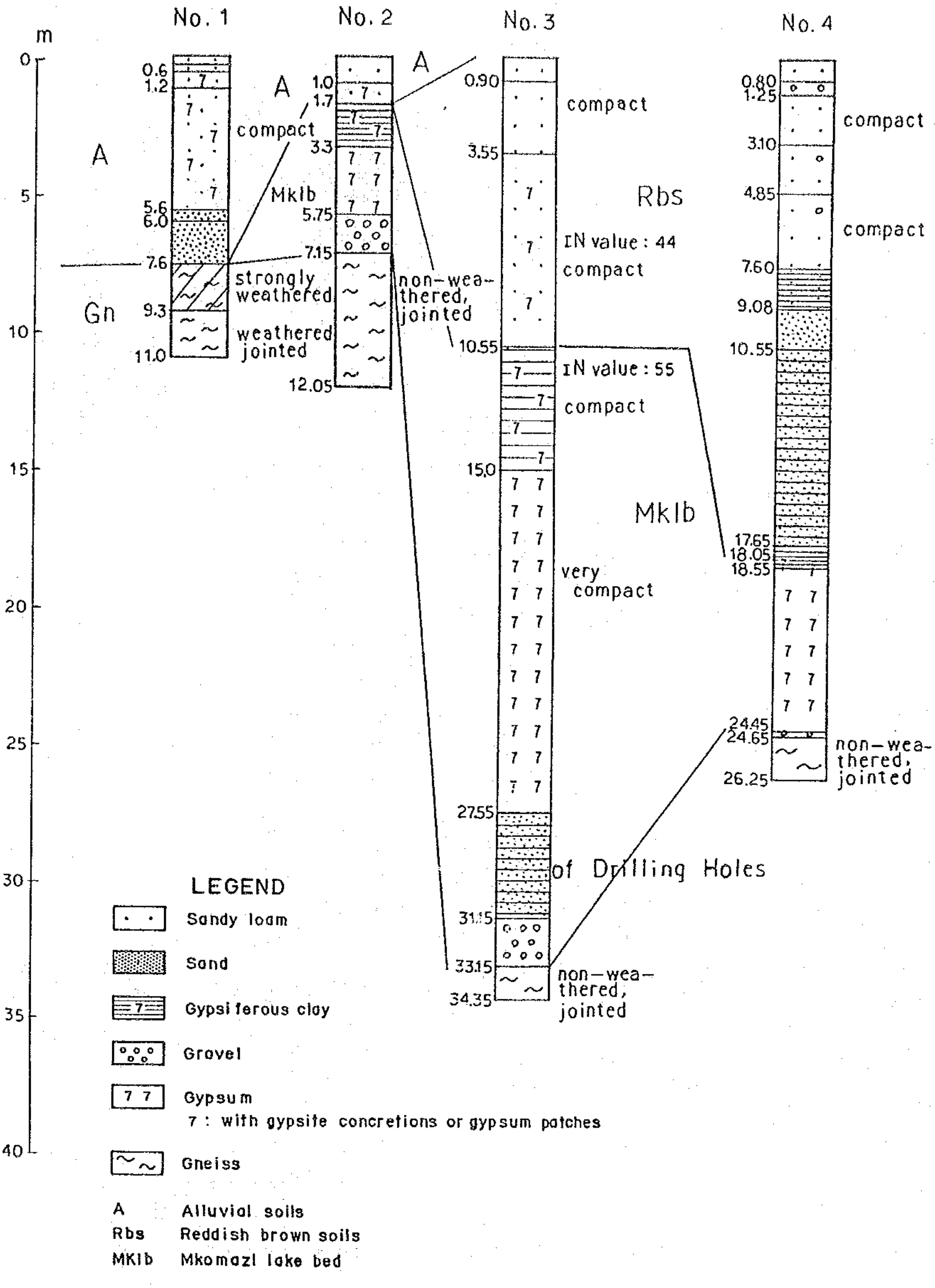


Fig. B-11 GEOLOGIC COLUMNAR SECTIONS OF DRILLING HOLES IN PROPOSED IGOMA DAM SITE

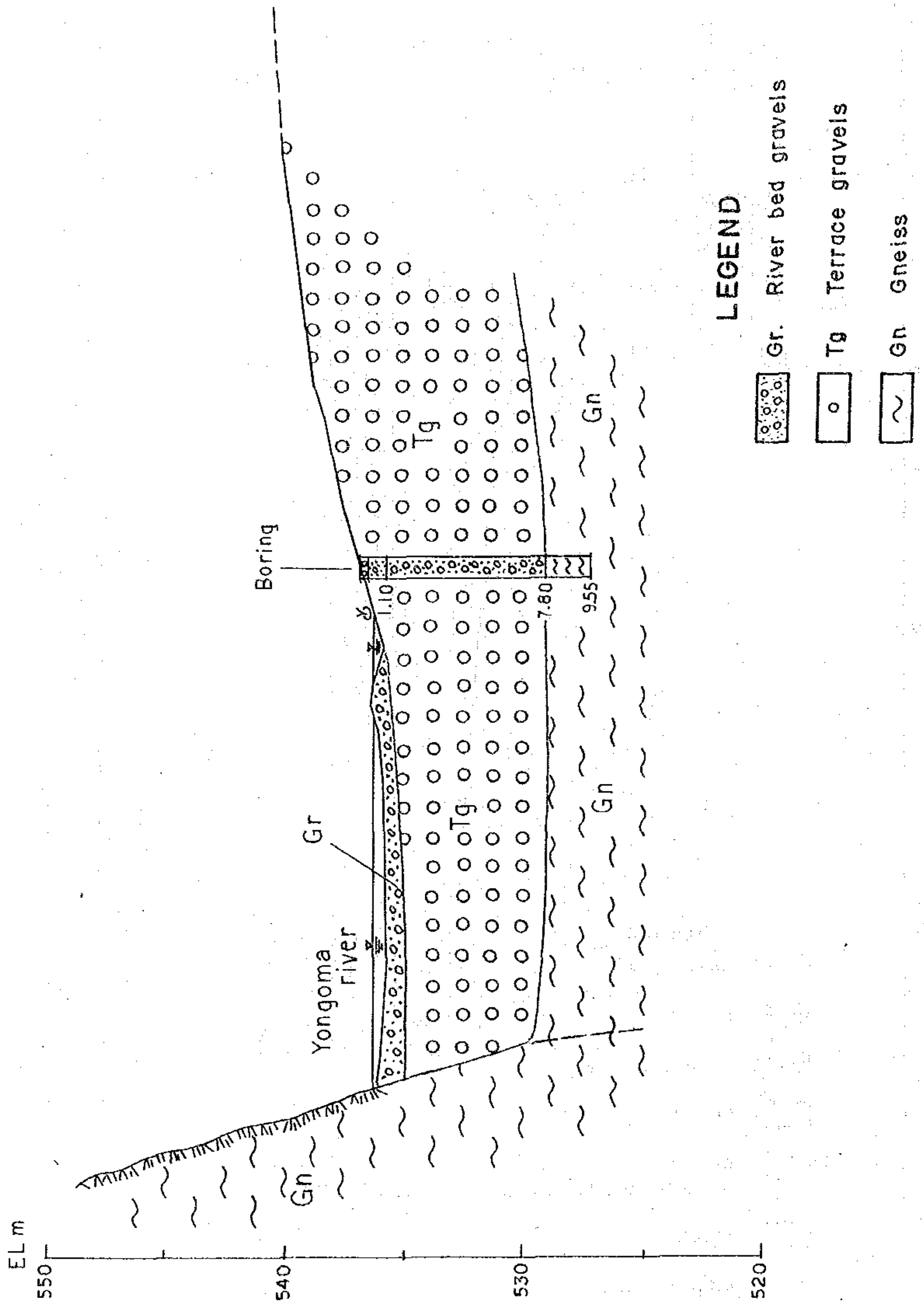


Fig. B-12 GEOLOGICAL SECTION OF YONGOMA DIVERSION WEIR SITE

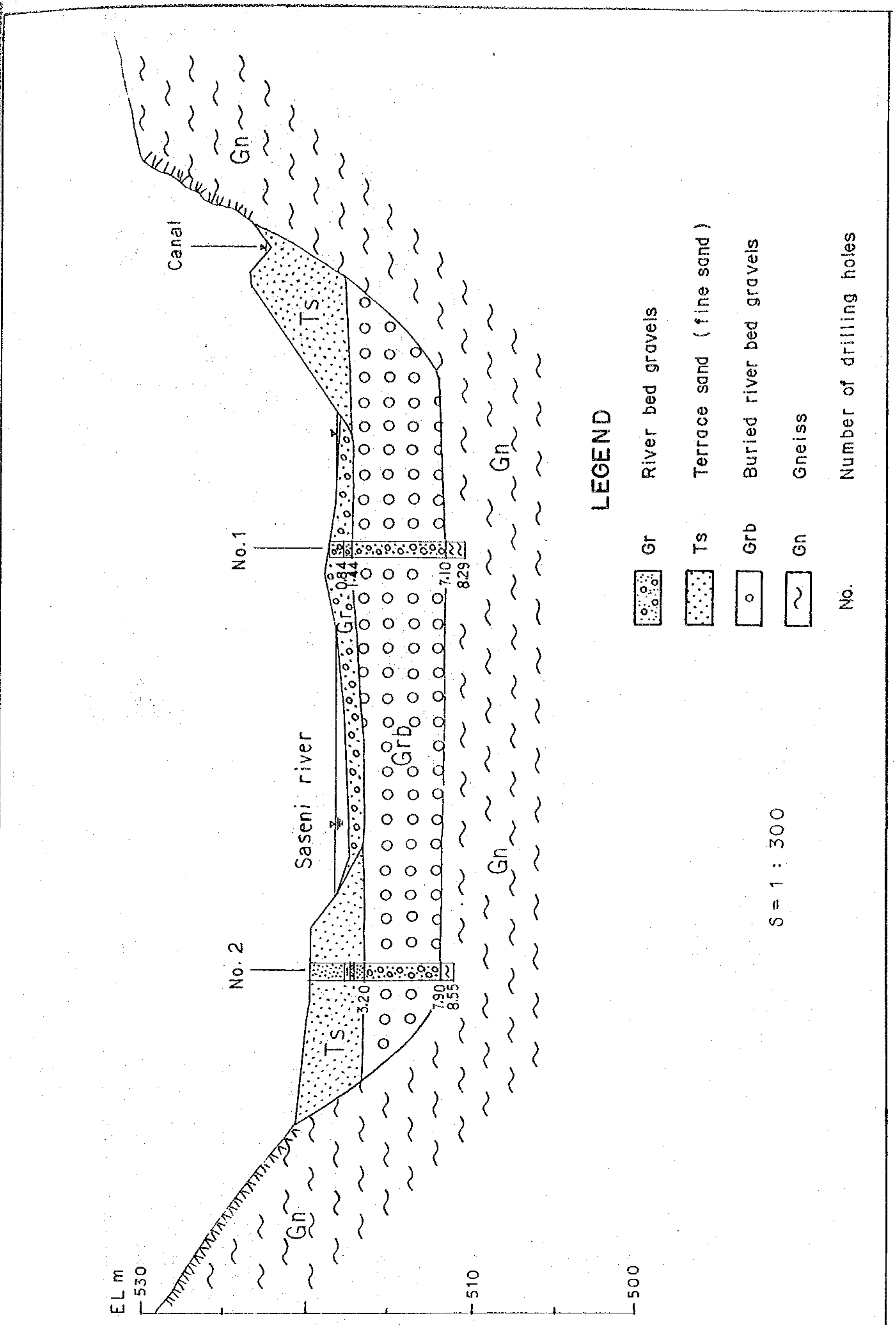


Fig. B-13 GEOLOGICAL SECTION OF SASENI DIVERSION WEIR SITE

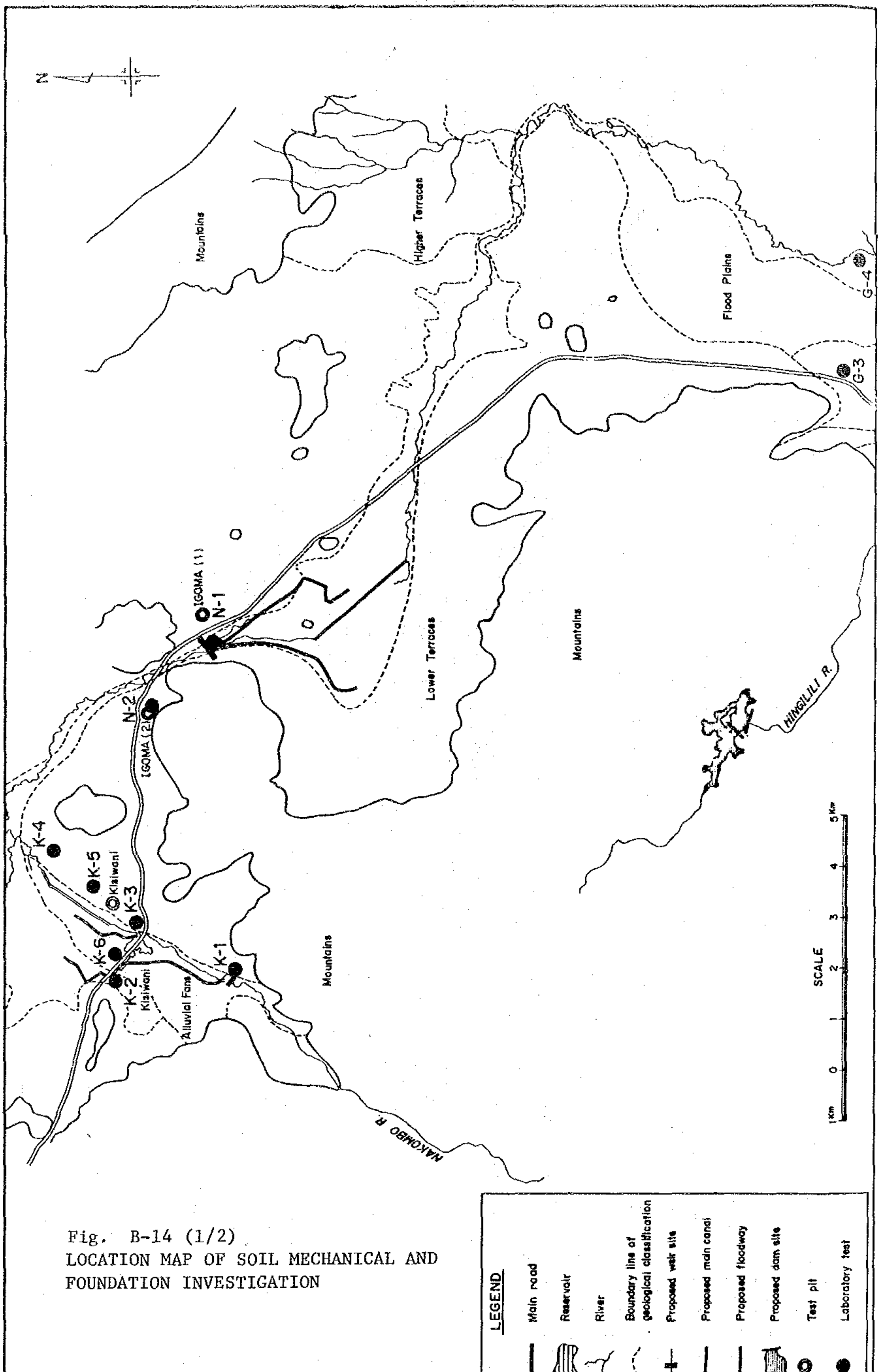


Fig. B-14 (1/2)
LOCATION MAP OF SOIL MECHANICAL AND FOUNDATION INVESTIGATION

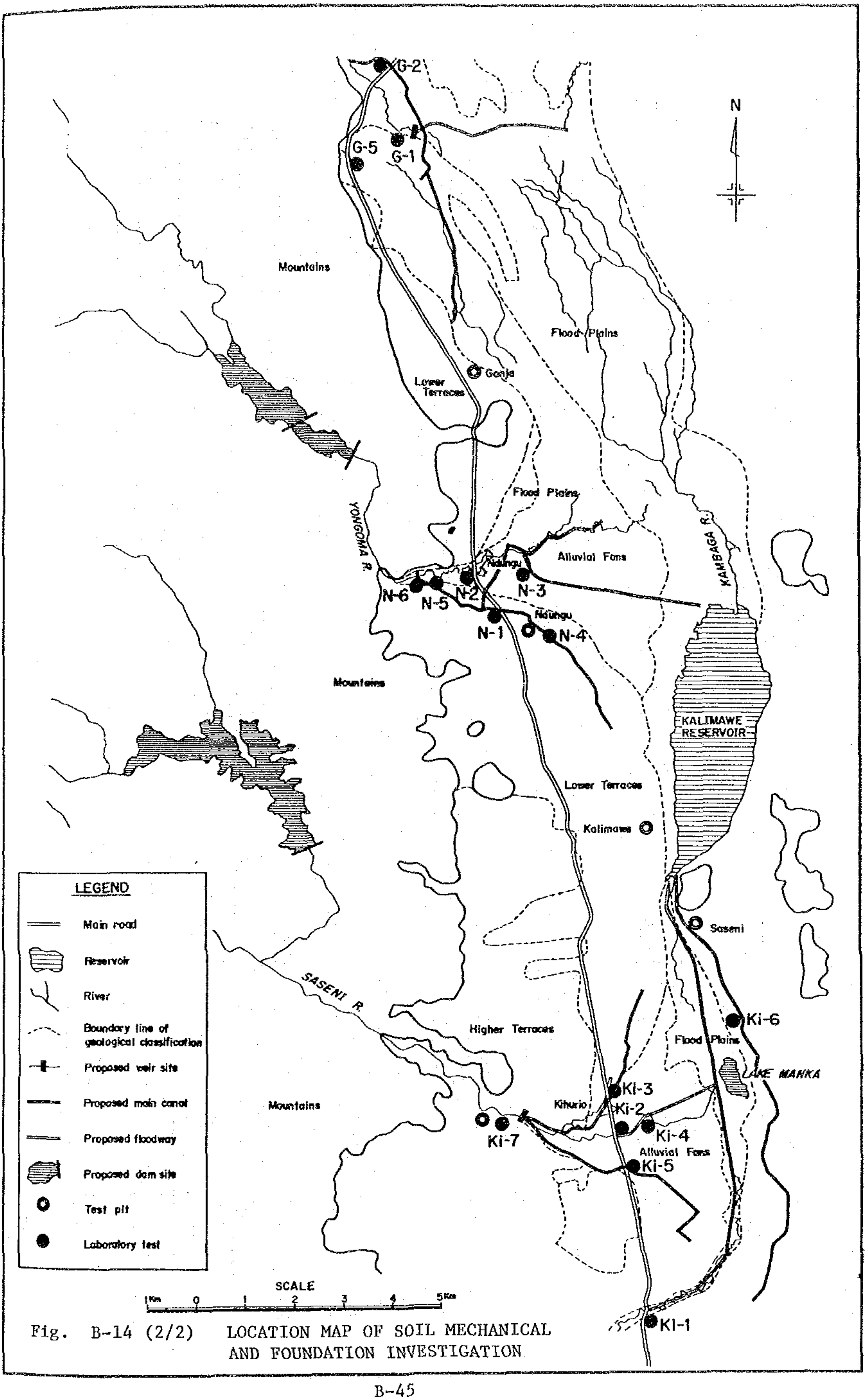


Fig. B-14 (2/2) LOCATION MAP OF SOIL MECHANICAL AND FOUNDATION INVESTIGATION

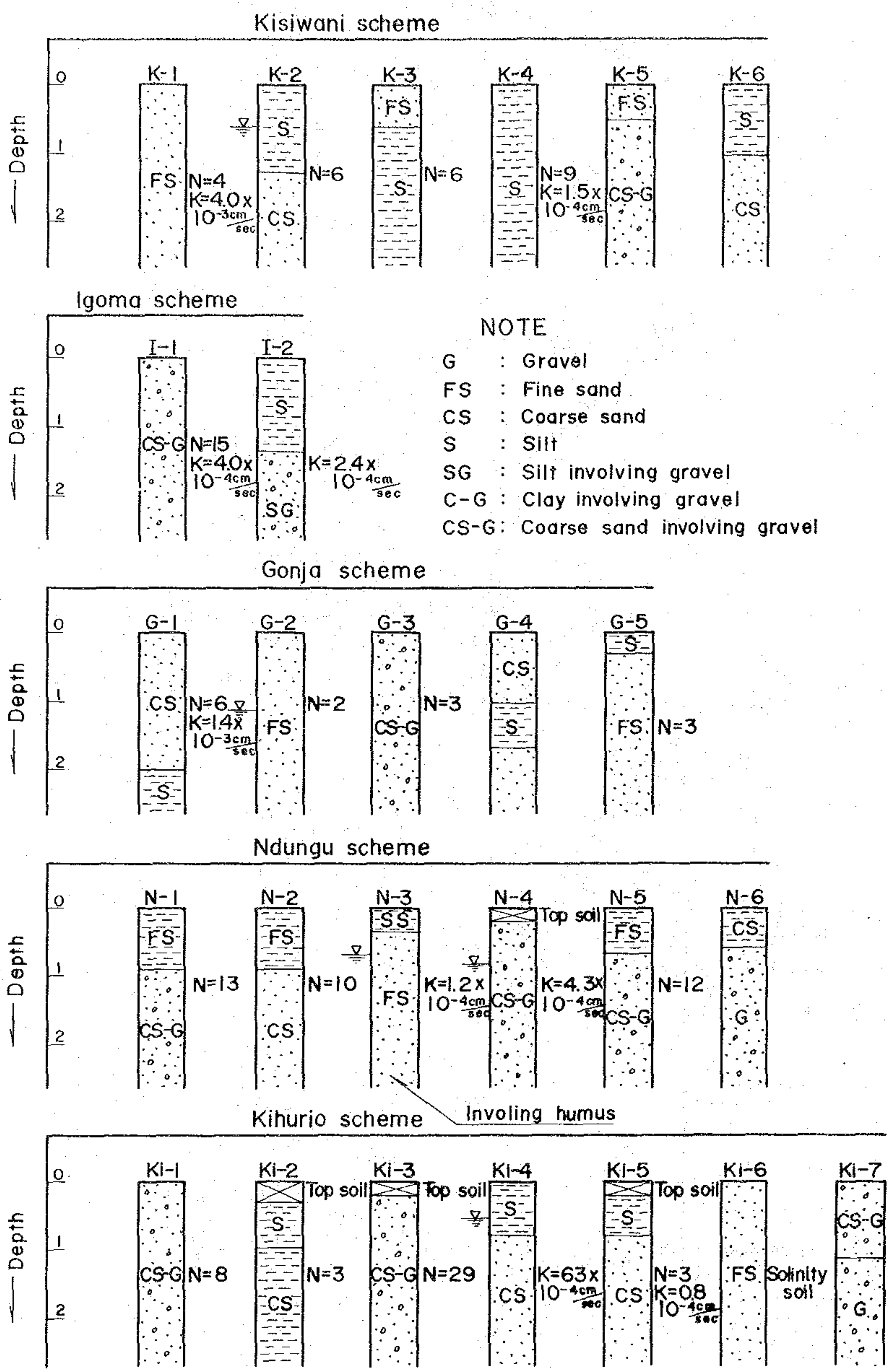
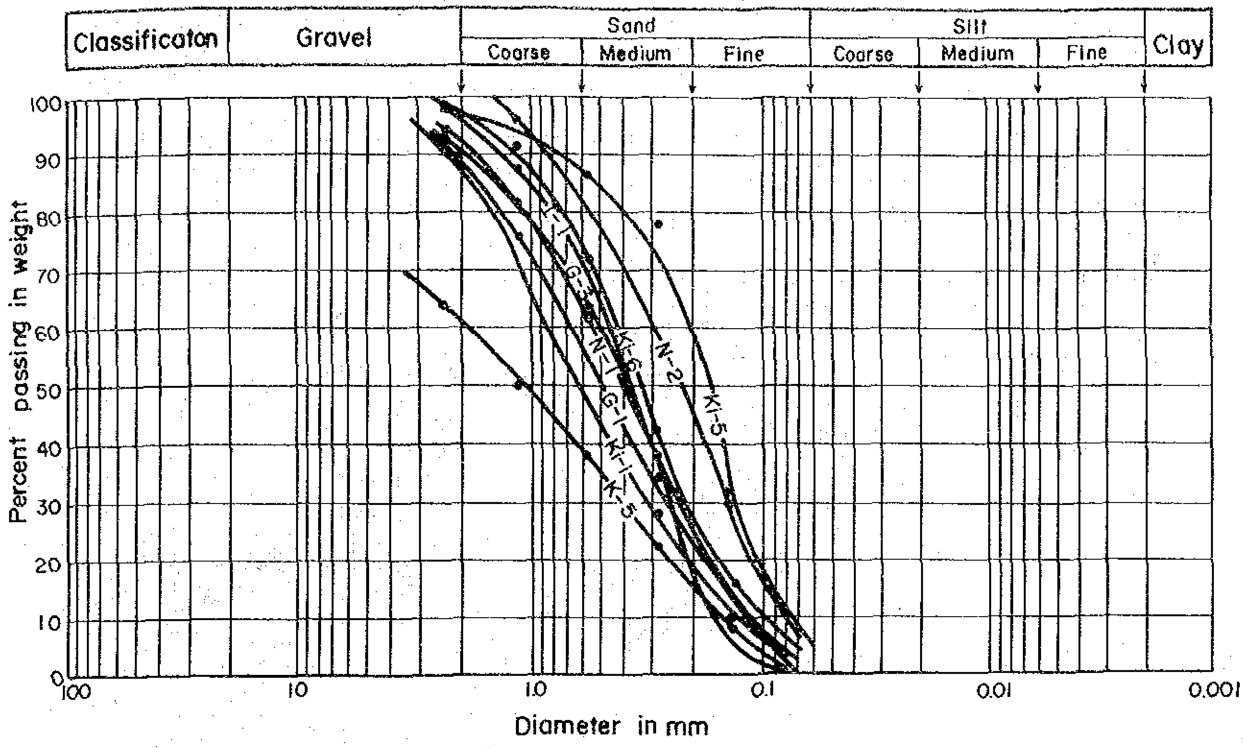


Fig. B-15 BORING LOG



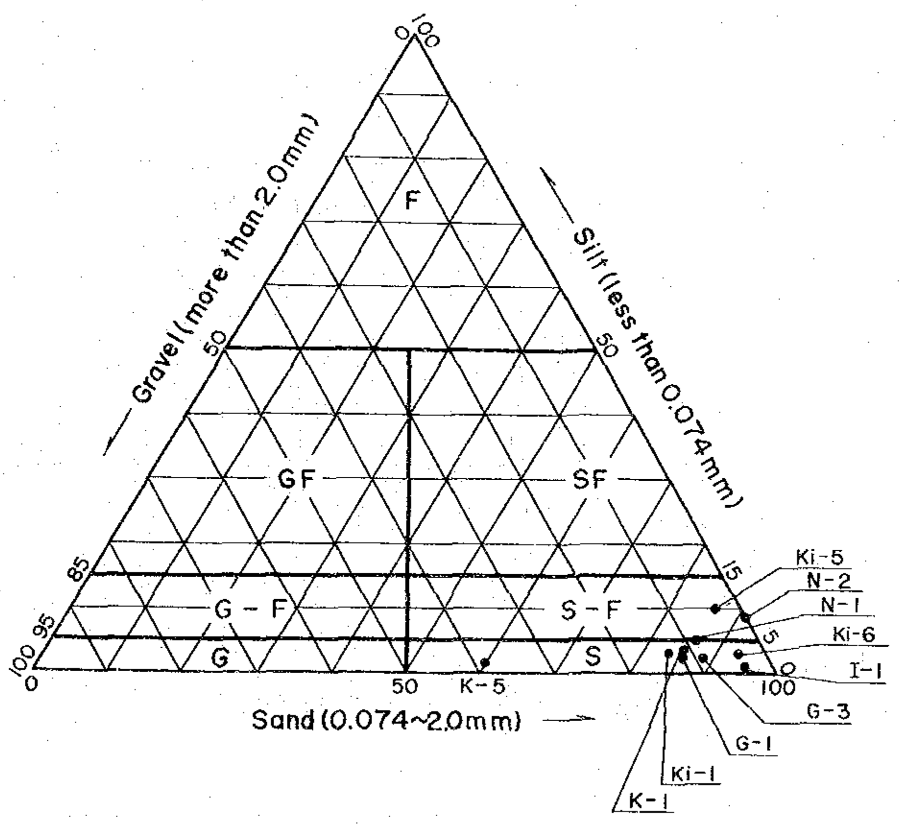


Fig. B-16 GRAIN SIZE DISTRIBUTION AND SOIL CLASSIFICATION

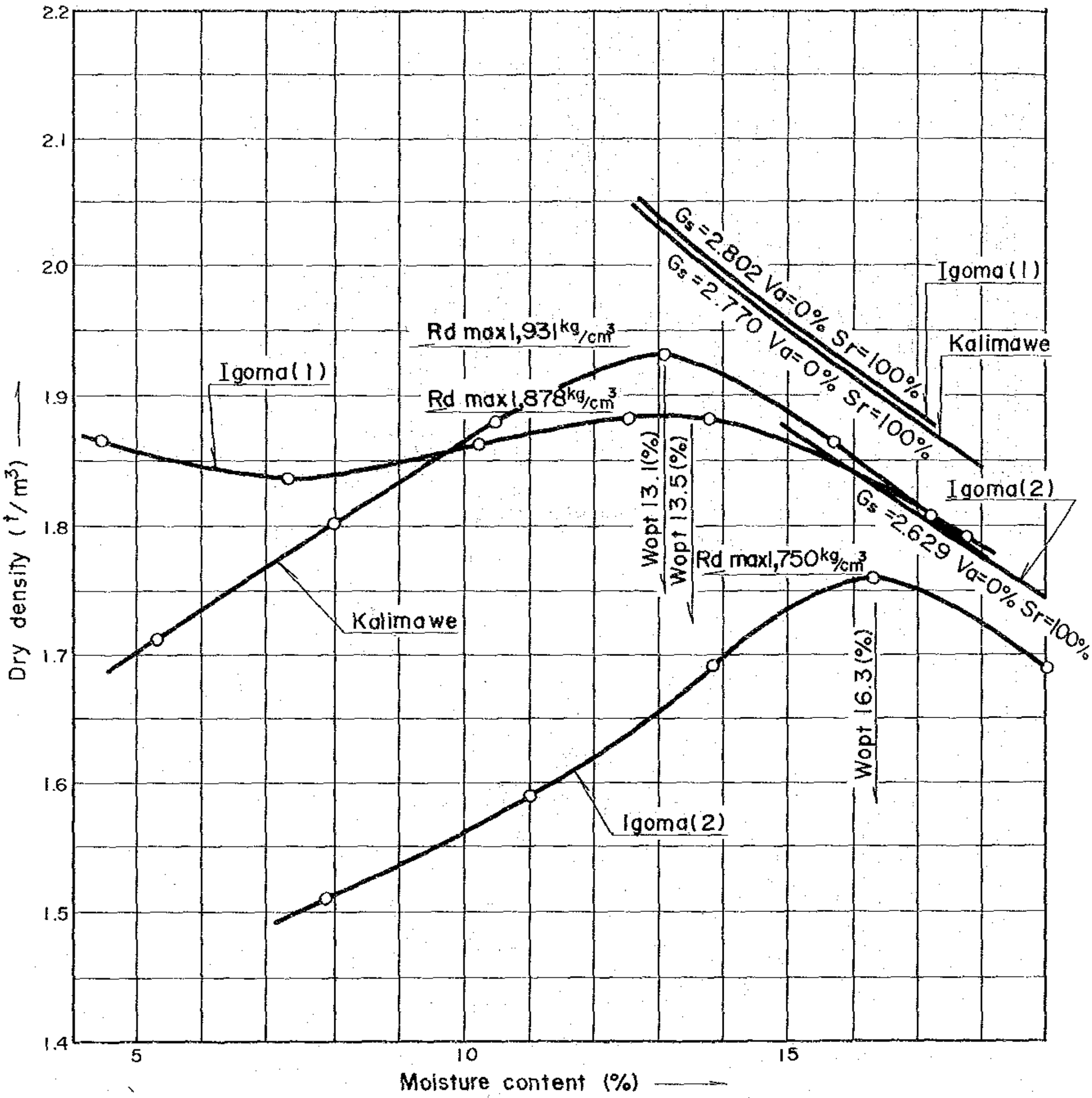


Fig. B-17 COMPACTION CURVE

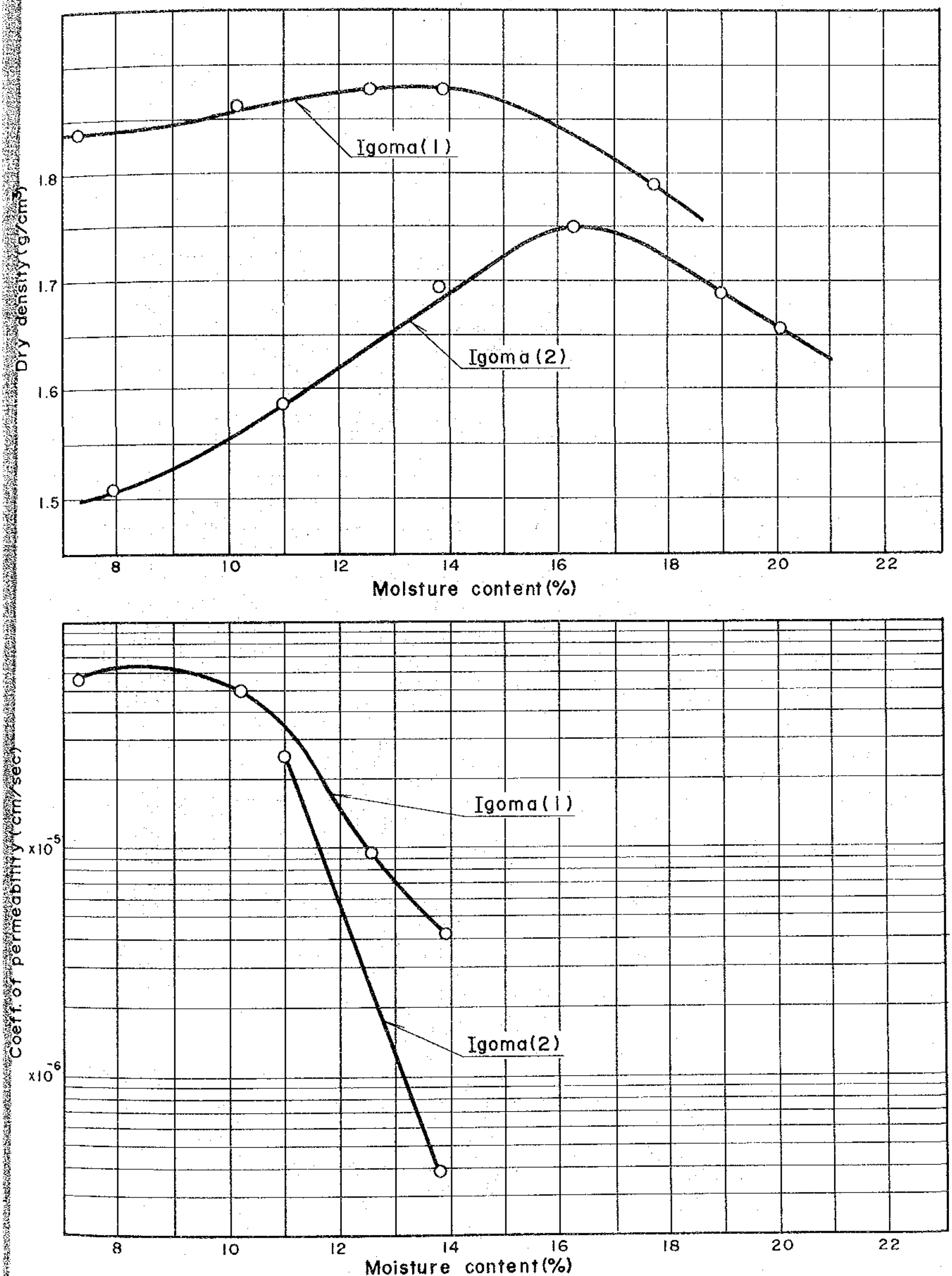


Fig. B-18 PERMEABILITY OF EMBANKMENT MATERIALS

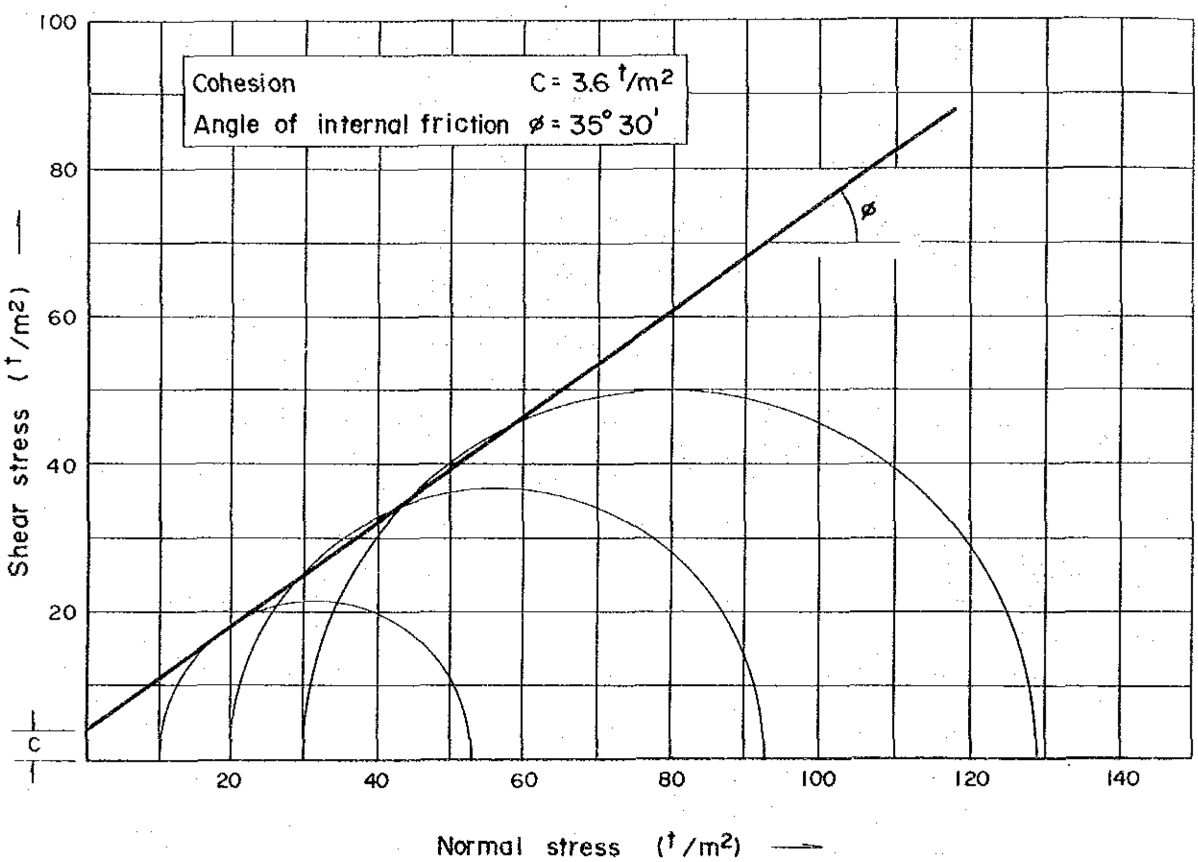


Fig. B-19 UNDRAINED SHEAR TEST (UU)

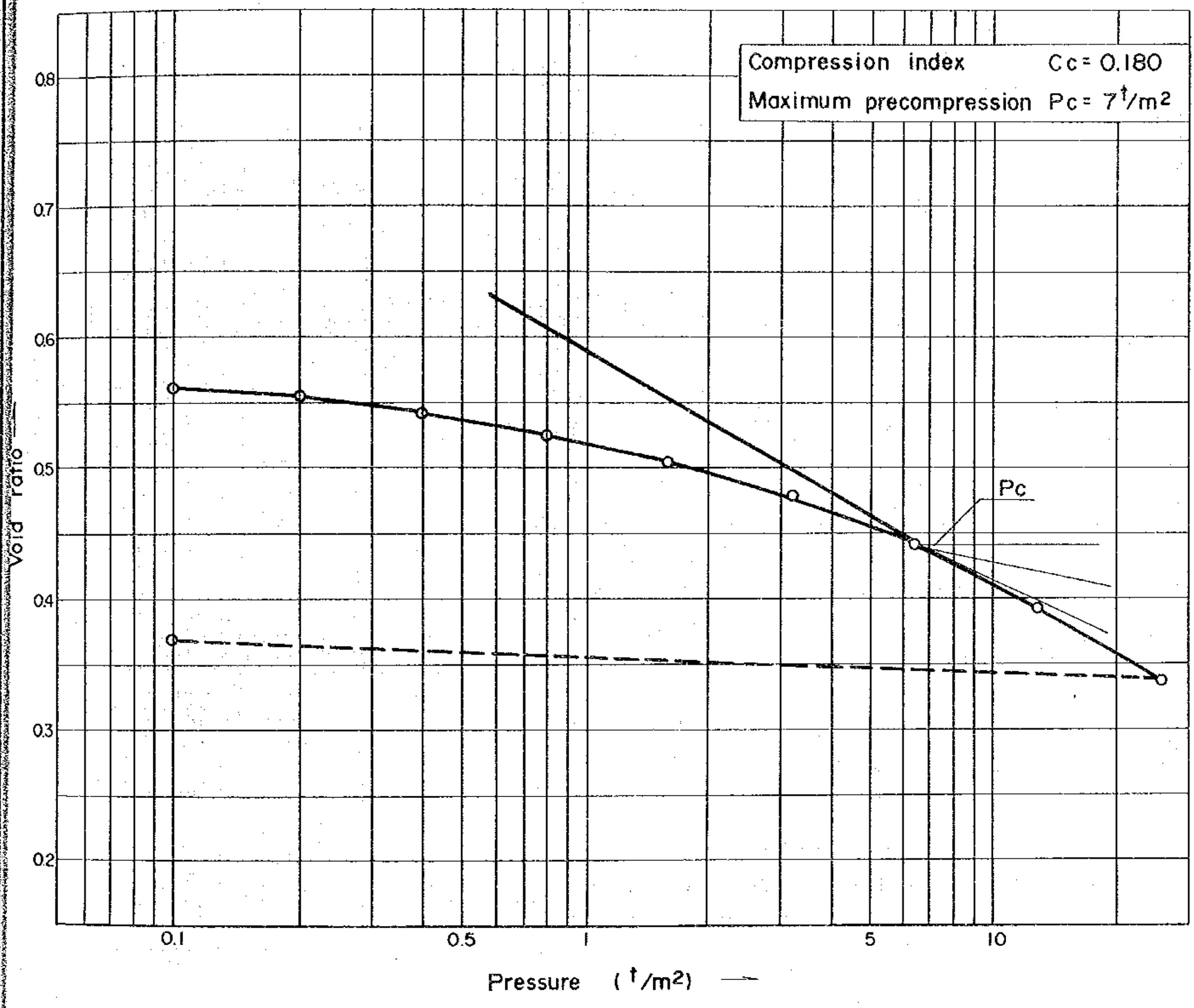


Fig. B-20 VOID RATIO - PRESSURE CURVE (CONSOLIDATION TEST)

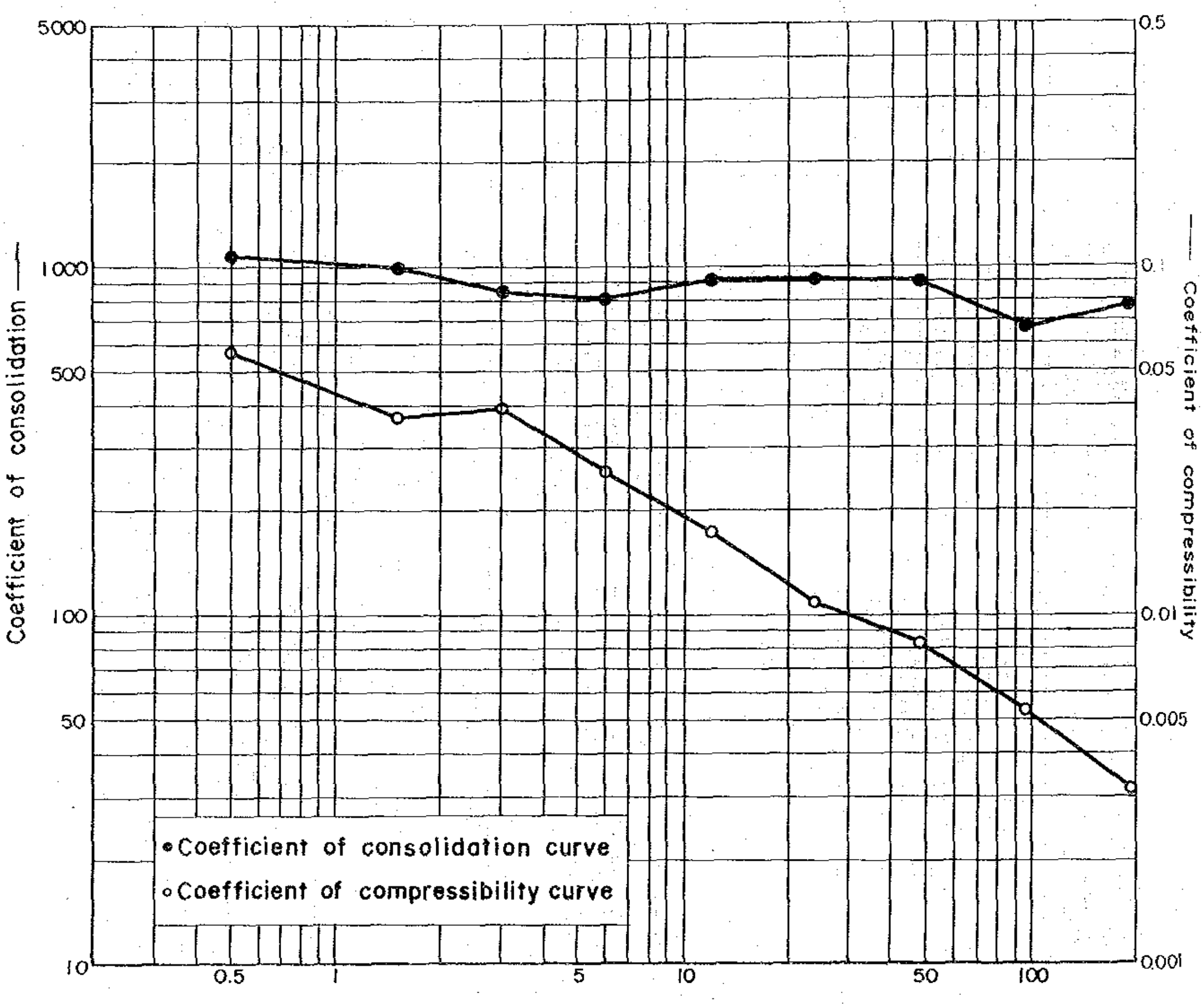


Fig. B-21 COEFFICIENT OF CONSOLIDATION - PRESSURE CURVE AND COEFFICIENT OF COMPRESSIBILITY - PRESSURE CURVE (CONSOLIDATION TEST)

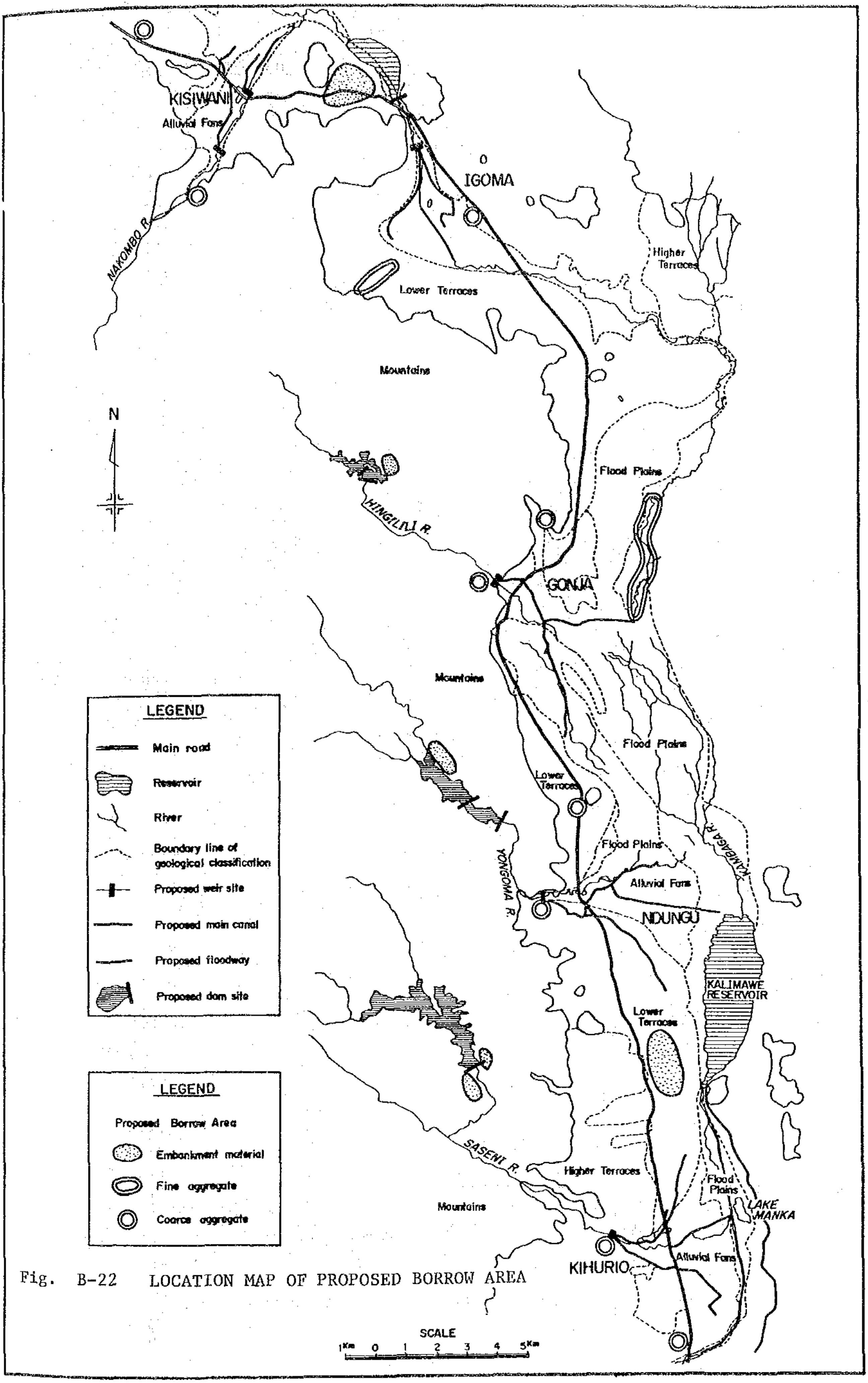


Fig. B-22 LOCATION MAP OF PROPOSED BORROW AREA

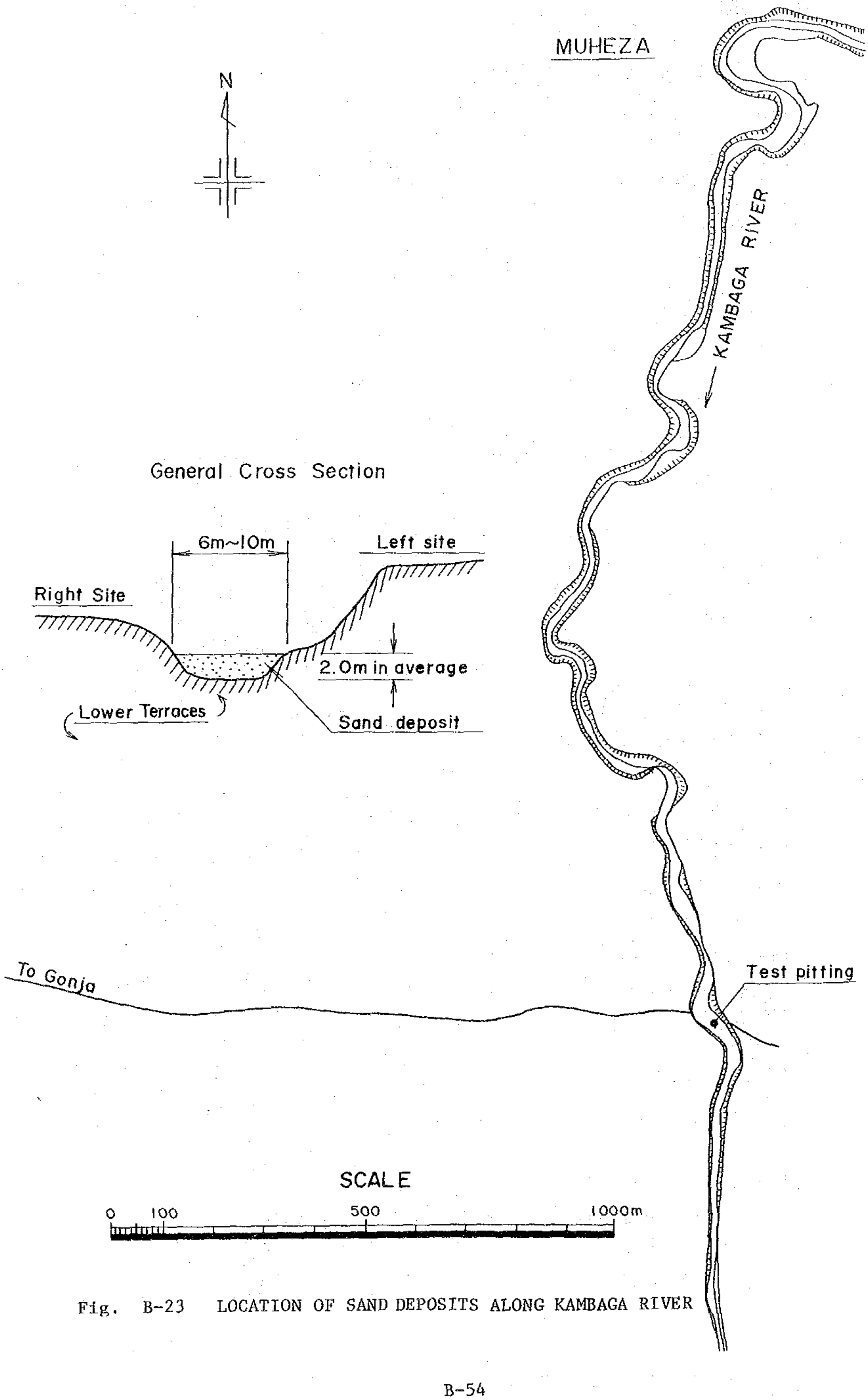
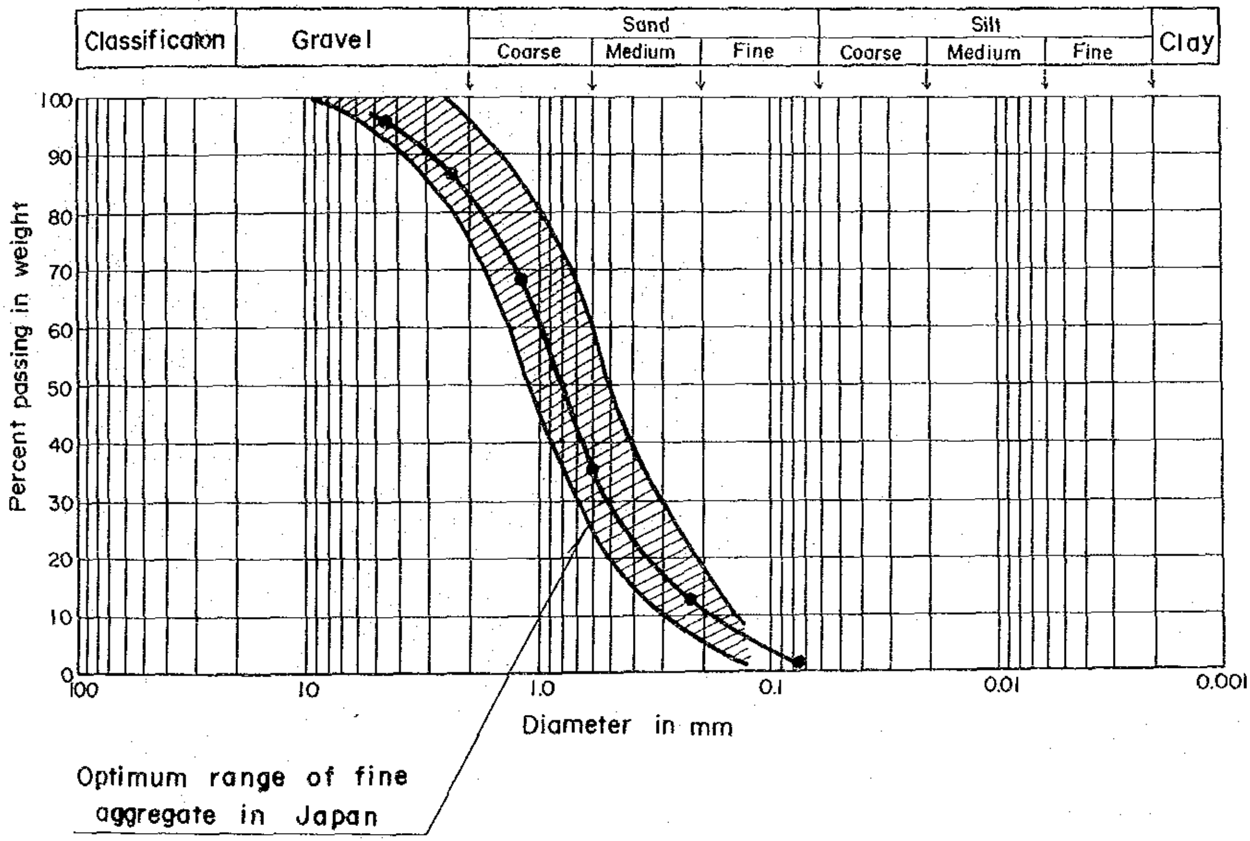


Fig. B-23 LOCATION OF SAND DEPOSITS ALONG KAMBAGA RIVER



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ANNEX C

SOIL AND
LAND SUITABILITY CLASSIFICATION

ANNEX C

SOIL AND LAND SUITABILITY CLASSIFICATION

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1. GENERAL

The primary soil investigation in the Mkomazi Valley area was conducted in 1963 by the Land Planning Office of the Kilimanjaro Region, in a course of the development planning for the Gonja Irrigation Scheme, which had been prepared by the Regional Water Engineer for Water Development and Irrigation Division of the Ministry of Agriculture. This soil investigation covered approximately 405 ha of Gonja village area and clarified that the soils in the Scheme area are quite capable of growing paddy and upland crops, although attention should be paid to the drainage control, particularly in the lowlying land.

To extend the above land assessment to the objective development area and to assist proper planning of the development schemes, the present soil investigation is programmed as an essential study on the Mkomazi Valley Area Irrigation Development Project. The present soil investigation is carried out, covering approximately 8,560 ha of which 7,700 ha is from November 1982 to January 1983 and remaining 860 ha is May to June 1983, in conformity with the soil survey manual prepared by the U.S.Department of Agriculture. The soil profile survey and sampling are performed by making exploratory pits and by the use of hand augers of 15 cm diameter. The profiles are examined to a depth of about 1.5 to 2.0 meters and to an average density at about one profile per 100 ha. In the course of the profile examination, some 112 soil samples were collected from major horizons or layers. Moreover, three groundwater samples are also taken from the representative shallow profile for checking the salinity and alkalinity. These soil and groundwater samples are tested for their degree of salinity and alkalinity by the use of pH-meter and EC-meter at the field laboratory which is temporarily set in the KADC Administration Building in Moshi. Out of 112 soil samples, 15 representative samples, were selected based on the results of field soil examination and sent to Tokyo for further detailed chemical analyses. The results of these detailed chemical analysis are shown in Figs C-1 and C-3 and Tables C-1 and C-2.

The present soil classification is made refering to "the Soil Taxonomy" system defined in 1953 the Soil Conservation Services, U.S. Department of Agriculture, 1975, in accordance with the request of the Regional Agricultural Development Office, Kilimanjaro Region. The land classification for the specific purpose of establishing the extent and degree of land suitability for sustainable irrigation farming is made in conformity with the land suitability classification system defined by the Bureau of Reclamation, U.S.Department of Interior and modified in 1967, particularly for appraisal of lowlying wet land.

The detailed topographic map (1:5,000), which was prepared by JICA in February 1983 is used for the mapping of soil and land classes. The boundaries of soil and land units are defined according to the information obtained through the field investigation and aerial photo interpretation.

2. GENERAL CONDITIONS OF SOIL AND LAND

From the geomorphological viewpoint, the Mkomazi Valley area is broadly classified into four land units, i.e. (1) quaternary plateau, (2) relict hills, (3) alluvial fan and (4) alluvial plain. The quaternary plateau is further classified into two land sub-units, i.e. dissected higher terrace (1.a) and lower terrace including small scale colluvial fan formulation (1.b). The alluvial plain is also sub-classified into natural levees (4.a), recent alluvial plains (4.b) and alluvial depressions (4.c).

Of the land units classified above, alluvial fans (3) are the most important for future agricultural development. The major fans extended in the valley area are Kihurio, Ndungu, Gonja and Kisiwani and these are respectively fed by Saseni, Yongoma, Hingilili and Nakombo rivers which are tributaries of the Mkomazi river. The land of these fans generally has very gentle slopes ranging from less than 1%. Mesorelief and/or slight undulations are found along the old river trails. These fans primarily consist of fine textured alluvium which is derived from the weathered gneissose in pre-cambrian formations. These alluvium have been recently put under the soil forming process with the oxidation weathering. As the results, cambic formations are weakly developed in the shallow surface profile. With the exceptional soil formation other than the cambic formation, the alluvium particularly deposited in the lowlying area has been put under the saline and alkaline soil forming processes which might cause a raising of brackish groundwater to the soil surface.

The lower quaternay terrace (1.b) is the land which mainly extends over the upper slope of the project area. Generally, the land has a gentle slope of less than 4% but has been dissected to rather small tracts by numerous shallow gullies. The soils of this terrace are primarily the loam to light clayey colluvium directly transported from the Mt. Pare chain. These colluvium have been put under the soil forming processes with strong oxidation weathering under the monsoon savanna climate, and cambic soil formation is weakly developed in rather shallow profile. With the small exception where the land has been recently cultivated with traditional irrigation practices, the colluvial soils are put under the hydromorphic soil forming processes. As the result, the soils have changed their colour from hue 2.5 YR to hue 5 and 7.5 YR in most cases. Besides, ferruginous mottling has proceeded in the shallow surface profile. No salinization and alkalinization are found in this irrigated soil.

The recent alluvial plain (4.b) is rather narrow land extending over along the Mkomazi river. The land of this plain has a flat or nearly flat topography and flood water stands in certain period during the rainy season. The soils are of recent alluvium having a heavy clay texture. Seasonal water stagnation has put these alluvium under the soil forming process of the hydromorphic weathering. Salinization and alkalinization of soils have also proceeded on this hydromorphic soil formation.

The alluvial depression (4.c) is practically a part of the recent alluvial plain. Due to the lack and/or small capacity of the natural drainage system in this area, the seasonal flooding is great for more than eight months from December to July, and the land forms marshes in the remaining months. Such seasonal waterlogging has put the fine textured alluvial soils in a strong gley formation. No salt accumulation is so far observed for this soil. With no exceptional cases other than the above, extremely strong salinization as well as alkalinization of soils has proceeded perfectly in the narrow area for the land surrounding this alluvial depression.

The land units other than the above, dissected higher terraces (1.a), relict hills (2) and natural levee (4.a) are relatively few. The dissected higher terrace is primarily the quaternary plateau developed at the foot of the Mt. Pare chain. Because of the rather steep topography in this terrace, the soils are being seriously eroded by strong showers, and hence sandy residuals with boulders, stones and gravels shallowly overlie the pre-cambrian basement at present. Psammophytic vegetation stands scarcely.

The relict hills are primarily the gneissose cone dissected in the quaternary land formation stage. The general features of this land are quite similar to those of the dissected higher terrace.

The natural levees herein defined only extend narrowly along the Mkomazi river. The soils of this land unit are generally composed of fresh sands having medium to fine sized particles. Because of the frequent occurrence of seasonal flooding in the rainy season, and the contrasting shortage of soil moisture in the dry season, vegetation as savanna grasses and thorn-acacia brushes scarcely grows on these levees.

3. SOIL CLASSIFICATION

3.1 Unique Soil Properties for Classification

In reference to "the Soil Taxonomy" system, the following terms of soil features and properties are taken into account for the present soil classification and mapping in the Mkomazi Valley area.

(1) Parent material and/or lithological materials

The parent materials of all the soils are primarily gneissose in pre-cambrian formations. Gypsites, crystalline gypsum and gypsiferous sand are secondary materials particularly of the recent alluvium and colluvium.

From the lithological viewpoint, the soils in the entire Mkomazi Valley area derive from the following four materials.

- Recent alluvium:

Generally, these materials are deeply deposited in the flood plain and have 35 to 40% clay, 10 to 15% silt flactions and 45 to 50% sandy particles. With small exceptions, deep sandy sediment are also found in the natural levee.

- Old alluvium:

These are primarily the fan depositions. The specific particle size shows a rather wide range from 15 to 50% clay, 25 to 50% silt and 5 to 65% sand. Fine to small gravel and/or fragments are also found in certain shallow layer but less than 20% in common.

- Colluvium:

These materials consist of 30 to 35% clay, 10 to 15% silt and 45 to 50% sandy particles. Thin gravel or stony layers intercalate few positions in the shallow profile.

- Residuals:

These are primarily the diluvium originated from gneissose in the pre-cambrian formation. Because of steep topography, finer fractions of these materials have been outwashed by heavy shower. Thus, the present texture quality of these materials is of sandy in general. Various boulders, cobbles, coarce fragments, etc. also remain in the profile.

(2) Lithological sequence in the specific soil depth(150 cm)

As broadly stated in the preceding sections, all the soils except those in the dissected higher terrace and relict hills have deep profiles of more than 2 m. These profiles generally consist of several strata characterized by different sedimentations, of which sandy and/or gravel stratification in the shallow profile are the essential factor for definition as the lower categories of soil groups. Seasonal formation of groundwater (perched water) or seasonal fluctuation of the groundwater table in the shallow profile are also important factors for defining the classes of soil moisture regime in the higher categories of soil classification.

In the small exception, out-crop and/or shallow profile limited by the base rock is the factor for classifying Lithic sub-group particularly in the dissected higher terrace and relict hilly area.

(3) Specific soil formation and diagnostic profile features

Hydromorphic weathering, such as leaching process of inherent basis, salinization/alkalinization process, gleization and mottling caused by the seasonal fluctuation of groundwater and/or waterlogging in certain period, etc. is the essential feature of soils in the lowlying area.

Although still weak at present, the formation of cabmic horizon is a unique profile feature in the sub-soils in the alluvial fan deposits in particular. Mollic and Ochric epipedons are typical surface soils in the entire Mkomazi area.

(4) Environment

The predominant features area a monsoon savanna climate directly subject to the soil formation, in which soil moisture regime is specified as Aquic in the lowlying area, and as Ustic in the elevated area.

There is no data available on the soil temperature in the Mkomazi Valley area. However, it is considered that the soil temperature regimė might be grouped into Iso-thermic in specific class for all over the soils, according to the seasonal variation of air temperature, relative humidity, solar radiation, evaporation, etc.

Scarce vegetation with psammophytic shrub and thorn-acasia brushes subjects to severe erosion. On the contrary, dense swampy grasses return organic materials to the soils, so that mollic epipedon develops rather extensively in the lowlying area.

According to the specific terms of soil features presented in the above, the soil classification is as follows:

3.2 Soil Classes

Based on the unique soil properties and the soil profile features, the soils in the Mkomazi Valley area are primarily classified into the following two orders, six sub-orders, six great groups, and nine sub-groups in the higher categories of classification.:

Order	Sub-Order	Great Group	Sub-group
Entisols	Fluvents	Ustifluvents	Typic Ustifluvents
- do -	- do -	- do -	Mollic Ustifluvents
- do -	- do -	- do -	Vertic Ustifluvents
- do -	Aquents	Fluvaquents	Mollic Fluvaquents
- do -	Orthents	Ustorthents	Typic Ustorthents
- do -	- do -	- do -	Lithic Ustorthents
- do -	Psamments	Ustipsamments	Typic Ustipsamments
Inceptisols	Aquepts	Tropaquepts	Typic Tropaquepts
- do -	Tropepts	Ustropepts	Fluventic Ustropepts

Out of eight soil sub-groups, Typic Ustifluvents mainly developed on the alluvial terrace lying upper part of the alluvial fan formation. Mollic Ustifluvents are the alluvial soils developed on the narrow river trails and/or alluvial depression scattered in the upper part of the alluvial fan. These soils are generally associated with Vertic Ustifluvents and somewhat with Typic Psammaquents.

Mollic Fluvaquents are the predominant soils extended over the alluvial depression in the lowlying alluvial plain. These soils generally are in wet conditions for more than 8 months from mid-November to mid-August.

Typic Ustorthents are primarily the colluvial soils deeply deposited in the lower part of quaternary plateau. Lithic Ustorthents are the erodible soils in the dissected higher terrace of quaternary plateau. Generally, these soils are shallowly bottomed by the gneissose basement and have skeletal conditions.

Typic Ustipsamments are the typical sandy alluvial soils developed narrowly along the Mkomazi river.

Typic Tropaquepts are mottled soils mainly developed on the alluvial low terraces or old levees in the middle part of major fan formations. They are somewhat associated with Vertic Tropaquepts and/or Typic Torrerts.

Fluventic Ustropepts, which are generally referred to as Low Humic Gley soils, mainly extend narrowly along the old river trails in the middle part of fan formation.

Generally, the soils of each sub-group are correlated with one to two soil families at the lower soil category of this soil classification, according to the soil profile features and soil chemical properties specified in the Soil Taxonomy.

In the soil classification at the lowest soil categories, such as soil series, soil phase and soil types, some associated groups are also observed in each soil family. These soils are characterized and distinguished each other mainly by the degree of base saturation to the cation exchange capacity, degree of their inherent fertility, different distribution of soil particle compounds, etc. These soil conditions, particularly base saturation, and fertility will be directly modified in the future when the objective development is performed and such works as irrigation, drainage and also intensive farming practices are properly operated. Thus, in this soil classification, the soils in the lowest categories are excluded from symbolizing the soil unit and mapping.

The soils correlating with the soil classes defined herein are summarized in Table C-1, and the development of each soil is illustrated on the soil map attached to this report(Fig. C-2).

4. PRINCIPAL NATURES AND PROPERTIES OF SOILS

As stated in the preceding chapter 3, it is clarified that the soils in the Mkomazi area can be primarily classified into two soil orders, six soil sub-orders, six great soil groups, nine soil sub-groups and 11 soil families. In due consideration of the soil utilization for agricultural production and also of the soil suitability for irrigation development, the principal natures and properties of each soil group are explained in detail as follows:

4.1 Typic Ustifluvents

Typic Ustifluvents so classified herein are primarily the sandy to loamy alluvial soils that mainly develop on the alluvial terraces lying over the upper part of fan formation. Generally, these soils have a ustic soil moisture regime and iso-thermic soil temperature regime under monsoon savanna climate. The groundwater table is commonly deeper than 50 cm in profile, although some seasonal fluctuation can be observed. At present, almost all of the land in this soil area is being cultivated for agricultural production, such as maize, beans, mango and coconut trees, under the rainfed conditions.

These soils have the specific horizon sequence at Ap/C1/IIC in common. Ap horizon is an ochric epipedon having dark brown to brownish gray (7.5 YR 3/3 to 10 YR 4/1); sandy loam to loam; weak sub-angular blocky structure; soft and friable consistence when wet, clear and smooth boundary with the next C1 horizon. The thickness of this Ap horizon is about 25 cm on an average. A good rooting of crops is observed in this horizon. C1 horizon to a depth of about 50 cm is a sub-surface soils having dark brown to brown (7.5 YR 3/4 to 4/4); loamy sand to sandy loam; few mottling with chroma 4 to 6 at 2.5 YR ; rather loose structure; clear and smooth boundary with IIC horizon. The rooting in this horizon is rather poor and limited to only the upper half position. IIC horizon is practically in the sub-soil with its profile deeper than 150 cm. The soil of this IIC horizon generally has a silty clay to clay loam texture; rather compact but friable consistence when wet; with a plastic and sticky when wet; with a massive to very coarse blocky structure.

Regarding the chemical properties of these soils, the surface soil has less than 2% of organic carbon; 7.8 to 8.5 pH values; 10 to 15 m.eq. cation exchange capacity (CEC) and some 100% or less of base saturation degree. The exchangeable sodium percentage of less than 10 indicates that the soil is free from alkaline constraint. ECe value is less than 1.0 m.mho/cm/25 ^{o}C. The sub-surface sandy soils are also free from the alkalinity and salinity problems, with a low inherent fertility in general.

The soils to a depth of within 50 cm are well drainable but IIC sub-soil layer has low permeability at less than 10^{-4}cm/s. In the light of these hydrodynamic characteristics, the soils are considered as unsuitable for paddy cultivation. To successfully cultivate the upland crops with irrigation practices, attention should be paid to the soil conservation such as manuring, erosion control, etc.

In the Mkomazi Valley area, the soils of Typic Ustifluvents correlate only with the Sandy soil family. These soils are indicated by the serial soil number 1. which is temporarily set as the mapping symbol in the present soil map.

4.2 Mollic Ustifluvents

These soils develop mainly on narrow alluvial depression extending over the upper part of fan formation. The soils are also grouped into Ustifluvents but distinguished from the former Typic Ustifluvents by the mollic property in the surface soil. Finer texture quality, calcareous conditions are to be key features for correlating with the soil family of this soil group.

In general, these soils have a horizon sequence of A(p)/C/IIC, and groundwater stands at less than 50 cm deep in the profile. A(p) horizon with a thickness of about 30 cm on an average is a mollic epipedon having brownish black to very dark reddish brown colour (5 YR 3/1 to 2/3); silty clay to clay loam; weak, sub-angular blocky structure; slightly sticky and plastic; friable consistence when wet but rather hard when dry; diffuse and smooth boundary. C horizon to a depth of about 50 cm is a sandy soil which generally has a dull reddish brown colour (5 YR 4/3 to 5/3); loose and structureless; very few and fine mottles; clear and smooth boundary. IIC horizon is practically sub-soil, having a clay loam to silty clay texture; brown colour (7.5 YR 4/3 to 10 YR 4/4); rather compact; massive to very coarse blocky structure; friable when wet but rather hard consistence when dry; plastic and sticky when wet.

With regard to the chemical properties, these soils have moderate alkaline range at 8.0 to 8.5 pH throughout the profile. Their exchangeable sodium percent (ESP) is low at less than 5. Organic carbon is about 3% in the surface soil and less than 1% in the sub-surface soils. CEC is rather variable from 30 to 40 m.eq. in both the surface and sub-soil. Base saturation is estimated at 80 - 100% in the surface soil and around 80% in the sub-soils. Among the exchangeable bases, calcium carbonate is dominant at more than 60% of the total bases.

Hydrodynamic features of these soils are mostly similar to the former Typic Ustifluvents. In due consideration of the soil conditions presented above, the soils of this group are suitable for irrigated upland cropping but not recommendable for paddy cultivation, mainly due to low surface water retention capacity.

The extent of this soil area is indicated in the present soil map by the use of serial soil number 2.

4.3 Vertic Ustifluvent

Vertic Ustifluvents are primarily the recent alluvial soils deeply deposited on the alluvial plain of the Mkomazi river. These soils have no diagnostic profile features except such vertic characters as wide and deep cracking when dry and weak gilgai formation on the soil surface.

These soils generally have a deep profile of more than 2 meters and a specific horizon sequence at A/C. A horizon to a depth of about 50 cm is an ochric epipedon having grayish yellow brown colour (10 YR 4/2 to 5/2); heavy clay texture; rather firm consistence when wet and hard when dry; very plastic and sticky; compact and rather hardly consolidated. When dry, cracking form rather intensively with depth more than 35 cm and width more than 1 cm. The soil of C horizon is moist throughout the year and the soil consists of fine stratification and hardly compacted with massive structure.

These soils show a strong alkali-reaction ranging from 8.5 to 9.0 pH throughout the profile and a rather high salinity is observed with ECe values ranging from 4 to 8 m.mhos/cm/25°C. Their ESP are moderately high at 25 to 30 in the surface soil and 70 to 90 in sub-soil. Organic carbon is around 1.5% in the surface soil and 0.5% in the sub-soil. CEC is about 30 m.eq. Base saturation is estimated at 110% or more throughout the profile.

As for the hydrodynamic features, the soils have a high moisture holding capacity at more than 45% (at field capacity level: pF 1.8), and have a very slow permeability coefficient.

In the light of soil conditions stated above, it is considered that these soils are suitable for paddy cultivation, but are not recommended for upland farming. Seasonal flooding and poor internal drainage are the main constraints for upland crop cultivation. In the agricultural utilization of these soils, attention should be paid to soil desalinization and/or dealkalinization.

In the present soil map, these soils are indicated by the use of serial soil number 3. As for the lower category of this soil classification, it is recognized that the soils are correlated with Clay, calcareous soil family of Vertic Ustifluvents. Besides, these soils are somewhat associated with Mollic Fluvaquents.

4.4 Mollic Fluvaquents

These soils are the typical wet soils developed in alluvial depressions. Since deep flood water stands for more than 6 consecutive months during the period from mid-November to mid-August, the land of this soil area is waste fallow and densely covered with swampy grasses.

Generally, these soils have no diagnostic profile features except rather thick mollic epipedon in the surface profile. The soils consist of fine particle alluvium throughout the profile. The soil of mollic epipedon has brownish black colour (5 YR to 7.5 YR 3/1 to 2/2); clay texture; weak sub-angular to blocky structure; plastic and sticky; rather friable when wet but hard consistence when dry. The thickness of mollic epipedon is about 25 cm on the average and the boundary with Cg sub-soil layer forms mostly clear and smooth in common. Cg sub-soils are light gray to grayish yellow brown colour (10 YR 5/2 to 6/2); clay to silty clay; massive structure; and a very plastic and sticky; and a very hard consistence when dry.

With regard to the chemical properties, the soils generally show strong alkaline reactions ranging from 8.5 to 9.2 pH throughout the profile. ECe values are rather variable throughout the profile and also between at locations, but do not exceed 4 m.mhos/cm/25°C.

With the special exception, these soils have been put under the salt accumulation process, and hence, the surface soils are, more or less, affected by salinity cum alkalinity. These soils mainly extend on the lowlying seasonal marshes in the Kihurio village area. The soils show high EC values ranging between 5 to 20 m.mhos/cm/25°C at the surface and these values gradually decrease with profile depth. The soil reaction ranges between 8.5 and 9.5 pH which also indicates that the soils are strongly alkaline throughout the profile.

Taking into account the soil features stated above, it is considered that these soils are particularly suited to paddy cultivation, although a rather high capital investment will be required for drainage improvement. To realize the optimum production of upland crops, both surface and internal drainage improvement are indispensable in this soil area. As for the special soils which are strongly affected by salinity cum alkalinity, proper soil amendment, particularly for modification of soil salinity by means of leaching practices, is required throughout the period of sustainable farming.

In the present soil map, these Mollic Ustifluvents are sub-classified into the two soil families of a Clayey family and a Clayey, Saline and Alkaline family. These development areas are indicated by the respective use of the serial soil numbers 4 and 5.

4.5 Typic Ustorthents

Typic Ustorthents are primarily reddish brown colluvial soils deeply deposited on the lower quaternary terrace. At present, almost all of the land of this soil area lies in waste with no agricultural production and is covered with scarce acacia shrub and short savanna grasses.

The general horizon sequence of these soils is A/C with practically no diagnostic features in the soil profile except thin gravel stratification in the shallow profile. A horizon is a ochric epipedon having dark reddish brown colour (2.5 YR 3/3 to 3/6); loamy sandy texture; weak and fine blocky structure or mostly structureless; very friable consistence when wet and soft when dry; clear and smooth boundary. A thickness of this horizon is about 20 cm on an average and the boundary with the next C horizon is clear and smooth form in common. C horizon generally consist of reddish brown loamy soils (2.5 YR 4/6) and thin gravel layers intercalate some 30 to 50 cm interval within 1.5 meters of profile. The soils of this horizon are compact and structureless. In the profile deeper than 1.5 meters, gypsum accumulates and forms crystaline patches.

As for the chemical properties, the soils show slightly to strong alkaline reactions at location by location, while mostly at less than 4 m.mhos/cm/25°C in ECe values throughout the profile. Organic carbon in the surface soil is low at 1.6%. CEC is about 35 m.eq. in surface soil and 27 m.eq. in sub-surface soil. Base saturation is estimated at about 45% or more.

The physical nature of these soils is favorable for irrigated upland farming, but not suitable for paddy cultivation. In the agricultural development, attention should be paid to the land and/or soil conservation with respect to erosion control. Proper manuring is also required for production increases.

The soils of this Typic Ustorthents are illustrated with serial soil number 6 in the present soil map attached to this report. In the classification of lower category, these soils are correlated with the Loamy family. Association with sandy or clayey families is also recognized to a certain extent. These association develop mainly on the narrow gullies and river trails, respectively.

4.6 Lithic Ustorthents

The soils herein are correlated with Lithic Ustorthents and develop on rather narrow area of the dissected higher terrace in quaternary plateau and the relict hills scattered in the entire Mkomazi Valley. These soils are primarily derived from loamy to sandy diluvium shallowly deposited on the pre-cambrian basement.

Generally, the soils have no diagnostic profile features except the erosion face and skeletal conditions as boulders, and a stony and gravel profile. The surface soil is sandy residue having a reddish brown colour (2.5 YR 4/6); many boulders and coarse fragments of gneissose; and thin at less than 25 cm deep of profile. This surface soil is sometimes absent in the profile because of heavy leaching by rain due to the scanty vegetation and steep topography. The second layer consists of fresh gneissose basement.

The land of this soil area is not suitable for agricultural development in the light of the soils as well as topographic conditions. In this soil area, reafforestation with such trees as cashew, eucalypt, etc. is the essential requirement so as to properly conserve the land particularly from the viewpoint of watershed management.

The soils of Lithic Ustorthents have a sandy skeletal soil family. The development of this soil group is illustrated in the present soil map by the use of serial soil number 7.

4.7 Typic Ustipsamments

The soils of Typic Ustipsamments develop on the narrow alluvial levee mainly extending over along the Mkomazi river. Generally, these soils have more than 1.5 meters deep of sandy strata which mainly consists of fine to medium sand particles. There are no specific profile features except several thin, finer stratifications.

The surface soil mostly to a depth of about 20 cm is an ochric epipedon having dark brown colour (7.5 YR 3/4); sandy loam texture; weak sub-angular to blocky structure; slightly sticky and plastic; friable consistence when wet. The lower layer is sandy sub-soil having brownish gray colour (7.5 YR 5/1 to 6/2), loose consistence. In this layer, intercalation of thin clayey to loamy stratifications is observed in some 20 cm to 35 cm intervals.

These soils show a strong alkaline reaction ranged from 9.0 to 9.5 throughout the profile, while quite low ECe at less than 0.5 m.mhos/cm/25°C. The groundwater table is as low at 2 or more even in the rainy season.

According to the soil conditions, the land of this soil area is considered unarable. In order to stabilize the present river course, reformation of gallery forest is required. To this end, cashew, eucalypt trees, etc., which have a high resistance to both drought and wetness, are recommended.

The soils of Typic Ustipsamments correlate with only the Alkaline soil family in the lower classification. These soils are indicated in the present soil map by the use of serial soil number 8.

4.8 Typic Tropaquents

The soils herein classified into Typic Tropaquents are typical wet Inceptisols developed extensively on the alluvial fan. These soils have been utilized for agricultural production since long ago. Besides, most half of these soils have been recently put under irrigation, although sustainable crop growth has not yet been achieved.

Generally, these soils have a gleyic and cambic horizon in the shallow profile. Under gleyic soil forming process, fine concretions of susquioxides develop in the gleyic horizon. Specific profile sequence observed in these soils is at A(p)/B/C. A horizon to a depth of about 25 cm is primarily the mineral soils having very dark brown to dark reddish brown colour (5 YR 2/3 to 7.5 YR 2/3); clay to clay loam texture; weak blocky structure; friable when wet but hard consistence when dry; plastic and sticky; clear and smooth boundary. B horizon, which is specified as the cambic pedon, is a gleyic soil having brown to grayish brown colour (7.5 YR 4/3 to 6/2); common and distinct fine ferruginous mottling; few to common, fine concretions of susquioxides; clay to silty clay texture; blocky structure; friable when wet but hard consistence when dry. C horizon is also a gleyic soil having dull brown colour (7.5 YR 6/3) to dull yellowish brown (10 YR 5/3); clay to clay loam, massive structure. The groundwater seasonally fluctuates within one meter of the shallow profile.

Regarding their chemical features, the soils are moderately strong to strong alkaline ranging from 8.0 to 9.0 pH; less than 4 m.mhos/cm/25°C in ECe value, indicating that the soils are free from the salinity. CEC of these soils ranges between 15 m.eq. and 35 m.eq. and the saturation degree of exchangeable bases is estimated at about 80% on an average. Groundwater stands at a depth of 50 cm and shows low salinity at less than 3 m.mhos/cm/25°C.

For the small exceptions where the land lies on the river trails particularly in the lower reaches of fan formation, the soils are affected by a moderately strong salinity. Poor drainage conditions are also the constraint on the present agricultural production.

In the light of the soil conditions stated above, these soils are quite suitable for paddy cultivation. To successfully realize the upland cropping, drainage improvement is the essential requirement in this soil area.

In this soil classification, an association with Vertic Tropaquepts and/or Mollic Fluvaquents is also observed in certain extent. With regard to the classification of lower category, clayey and moderately strong alkaline soil is defined as the most predominant soil family. The saline soil observed in the lowlying area is distinguished from the above family so as to clarify the agricultural constraint of these soils. Thus, in the present soil map, these two typical soil families are illustrated by the use of serial soil number 9 and 10, respectively.

4.9 Fluventic Ustropepts

Fluventic Ustropepts are soils mainly developed on the skirt of lower quaternary terrace. These soils are one of the dominant soils for the agricultural utilization and have been recently reclaimed to its potential maximum.

The soils are to be derived from the clayey colluvium deeply deposited under the fan formation. The specific horizon sequence of these soils is at A(p)/B/C in which B horizon is considered at cambic soil. A(p) horizon to a depth of about 25 cm is a mineral soil which is specified as ochric epipedon. The soils in this horizon are dark reddish brown (10 YR 3/2); clay to silty clay texture; weak sub-angular to blocky structure; friable when wet and rather hard consistence when dry; plastic and sticky when wet; gradual and smooth boundary. B horizon is generally deeper than 50 cm. The soils of this horizon are a dull reddish brown (7.5 YR 3/3); clayey texture; blocky structure; friable when wet but of hard consistence when dry; diffuse and with a smooth boundary. C horizon consists of reddish brown to brown coloured soils (7.5 YR 4/3) having massive structure. Groundwater table is deeper than 2 meters even in the rainy season in most cases.

As regards their chemical properties, the soils are slightly to moderately strong alkaline ranged from 7.5 to 8.5 pH and less than 1 m.mho/cm/25^{o}C ECe throughout the profile. Organic carbon in the surface is 2.5% and less than 1.5% in sub-surface soil. ECe ranges from 15 to 25 m.eq. Base saturation degree is estimated at 60 to 100%. ESP is estimated about 10 to 25.

With respect to their physical nature, the soils have a high moisture holding capacity ranging from 30 to 35% at the field capacity in condition. Permeability coefficient in the sub-surface soil ranges from 10^{-4} to 10^{-5} cm/sec in order. Taking into consideration the soil features above, the soils are suitable for cultivation of both paddy and upland crops.

In the present soil map, these soils are indicated by the use of serial soil number 11. These soils are predominantly correlated with clayey soil family in the lower category of this classification.

5. LAND SUITABILITY CLASSIFICATION

5.1 Basic Consideratons on Land Classification

The land classification for delineation of the potential arable area is made in accordance with the land classification system defined by the Bureau of Reclamation, the U.S. Department of Interior, 1953 as modified in 1967.

For the specification of the land defined in the above reference, the following soil and physical environments are taken into consideration as the essential terms for evaluation.

(1) Soil textural qualities (s): limitation due to coarse texture with gravel for economic development of paddy field with irrigation facilities, and/or limitation due to very fine texture for upland crops with irrigation.

(2) Effective soil depth (k): limitation due to sand, gravel, cobble, and/or rock formation and/or impenetrable sand layer within shallow depth below ground surface.

(3) Soil salinity and alkalinity (a): limitation due to strong saline and alkaline reaction, high exchangeable sodium percent and/or sodium adsorption ratio of the soils.

(4) Topography (t): limitation mainly due to unsuitable land elevation for economical gravity irrigation, and relief conditions unsuitable for economical field arrangement.

(5) Drainage (d): limitation mainly due to the seasonal flooding or very poor internal drainability caused by high groundwater table and heavy clayey texture.

Amoung the limiting factors above, seasonal flooding is the biggest constraint to the proper agricultural development, although present crop cultivation is more or less sustained by the use of flood water. Very poor internal drainage is caused by heavy clayey texture and the high groundwater table is also a limitaiton, particularly for the economic farming of upland crops. In order to develop the project area successfully, rather high capital investment is required for flood control and drainage improvement.

The main topographic constraints are the relief conditions in the quaternary plateau and relict hilly area. It is difficult to make economical field arrangement for proper irrigation farming mainly due to the steep slopes.

The fine textural features which consist of 35 to 50% clay, 30 to 45% silt and 15 to 25% sandy particles are generally accepted for paddy cultivation. However, the cultivation of upland crops is restricted to a certain degree due to unfavourable characteristics such as very low intake rate, very high moisture holding capacity, and very low permeability coefficient of soils.

The fine textured soils having a very hard consistence when dry, while very soft and friable consistence when wet, will also restrict the soil preparation work to some extent.

Coarse textured soils having a rapid percolation rate and a low moisture holding capacity, are also not suitable for economical irrigation development due to the large water requirements for maintaining a favourable range of soil moisture in a certain depth of the soil. Gravelly and stony soils in the quaternary plateau and relict hilly area will greatly limit the farm operaitons and the rooting of crops.

Shallow soil depth especially due to rock or stony layers will restrict not only the crop production but also an economical field arrangement. In order to reclaim these soils successfully, it is necessary to study the specific land use, from the viewpoint of land conservation.

Some other constraints are also found in the survey area, such as the prevalence of various pests and diseases, low familiarity of the farmers with the modernized farming practices and improved varieties of crops, low intensity of agricultural supporting services and so on. However these conditions can be excluded from this land classification study, concerning the purpose of this land classification.

5.2 Specificaion of Land Classificaiton

Taking into account the soil and land conditions presented in the preceding sections and also the plant physiological characteristics of paddy and upland crops, the terms of land classification and their specific degree of correspondence to the land suitability classes are established in accordance with the land classification standard defined by the U.S.Breau of Reclamation.

The criteria for rating of soil and land factors is tabulated in Table C-4. The terms of land classification and their specific degree of correspondence are summarized in Table C-5.

5.3 Land Classification

In rating the irrigation suitability of land, limiting factors of soil and land are assessed whether they are corrigible or difficult to involve in land development. Hence, the potential land suitability herein defined are graded by applying the lowest amount of limiting factors. In this context, physical features such as soil depth, soil texture, drainability, and chemical properties such as strong salinity and alkalinity, and topographic conditions are the essential limitaitons in the Mkomazi Valley area.

In light of the profile features as well as soil chemical and physical properties, the land of soil areas, i.e. Clayey and moderate alkaline soil family of Typic Tropaquepts (9) and Clayey mineral soil family of Fluventic Ustropepts (11) are involved in the highly suitable class (I) for irrigated paddy cultivation. Taking into account the plant physiological characteristics of paddy, alkalinity of soil family (9) is considered to be acceptable for normal growing the paddy plant.

The land of such soils as Clayey, strong alkaline and low humic soil family of Mollic Fluvaquents (4), and Clayey and moderately strong alkaline/saline soil family (10) of Typic Tropaquents is classified into suitable class for profitable paddy cultivation. Alkaline reaction of these soils is not a limitation to the paddy production. Besides, the salts accumulated in soils (10) could be reduced to capable range at less than 4 m.mhos/cm/25°C by proper operation of the leaching practices through intensive irrigaion. Drainage improvement is the essential work in this land class.

The land of soil families such as Fine loamy, calcareous and low humic Typic Ustifluvents (2), Clayey, calcareous and strong alkaline soils of Vertic Ustifluvents (3), Clayey, strong alkaline/saline and low humic soils of Mollic Fluvaquents (5) is also defined as arable land for paddy cultivation. From the drainage engineering point of view, however, the suitability grade of this land might be low at moderate (III) to marginal (IV) classes because of rather high capital investment required for flood protection and also rather expensive management cost of surface drainage during the cropping season particularly in the rainy season. If provide proper drainage system and operate sustainable irrigation for paddy farming, alkaline reaction of soils will be modified into the capable range without any use of special inputs. The salinity constraints can be also improved through intensive irrigation and drainage operation.

The other land correlates with the Sandy mineral soil family of Typic Ustifluvents (1), Loamy and strong alkaline soil family of Typic Ustorthents (6), Sandy skeletal family of Lithic Ustorthents (7) and Alkaline soil family of Typic Ustipsamments (8) are classified into unsuitable land class (VI) for paddy cultivation. The coarse texture quality is one of the essential limitations. Unduration or steep topography make the proper field arrangement for irrigation and farm operation difficult.

As far as the irrigation development for the upland cropping is concerned, the land suitability grades in each soil family could be made separately from the above classification, taking into account the specific irrigation practices and adaptability of the upland crops. The soils correlated with the soil families (6) and (11) are grade into the highly suitable class (I) and the soils (9) are put into the second grade (II). The soils classified into families (1), (4) and (10) could also grade as arable (III and IV) but profitable development cannot be expected because of the high capital investment and recurrent cost required for connection of seasonal flood or drainage constraints and amelioration or modification of salinity and alkalinity of soil. The soils defined as soil families (2), (3), (5) and (7) are graded as unsuitable land. These land have very scarce potential for crop production and/or little possibility of soil and land improvement.

From the above land evaluation, the land in the Mkomazi Valley area is preliminarily classified into five suitable land classes for irrigated paddy cultivation and four classes for upland crop cultivation as shown in Table C-6.

The first class is the highly suitable land (I). The land of this class practically has no limitation for future development in general, and high return on crop production can be expected with the project.

The second class includes the suitable land (II) in which sufficiently high productivity and profitability can be expected if the land is developed with irrigation. However, there are some limitations caused by alkaline reaction, poor inherent plant nutrients of nitrogen and phosphrorous elements in particular, and poor drainability of soils. These factors are likely to reduce the crop yield and/or to increase recurrent cost for the crop production and conservation of soil and land.

The third class is moderately suitable land (III). The land of this class is also expected to have higher productivity for both paddy and upland crops, although there are limitations which may reduce crop yield and call for higher recurrent cost for the farm operation and soil conservation. Seasonal flooding and/or water stagnation are the biggest constraint in this class land.

The fourth class (IV) is the marginally suitable land (IV). The land of this class is also expected to obtain a certain return from crop production. However, improvement of drainage conditions requires a large capital investment.

The last class is the economically unsuitable land (VI) for the objective irrigation development, because of the land having serious limitation such as deep standing of seasonal flood or shallow and stony soil or steep topography, etc.

6. DEMARCATION OF POTENTIAL ARABLE LAND

The 11 soil families preliminarily identified in the entire Mkomazi Valley area are distributed in the surveyed are, as shown on Fig.C-3 and tabulated below.

Unit: ha

Soil Families (Soil No.)	Sheme Area					Total
	Kisiwani	Igoma	Gonja	Ndungu	Kihurio	
(1)	90	-	-	70	-	160
(2)	-	140	-	-	-	140
(3)	70	-	-	50	250	370
(4)	250	-	470	250	270	1,240
(5)	-	-	70	-	170	240
(6)	230	200	400	260	330	1,420
(7)	20	60	-	10	30	120
(8)	-	-	870	200	-	1,070
(9)	140	170	610	530	620	2,070
(10)	-	-	230	250	30	510
(11)	-	290	150	180	600	1,220
Total Extent	800	860	2,800	1,800	2,300	8,560

According to the systematic appraisal of soil and land made in the preceding section 5, the land in the project area is classified as follows:

Soil Families (Soil No.)	Extent Area (ha)	Land Suitability Classes	
		for Rice	for Upland Crops
(1)	160	VIs	IIIs
(2)	140	IIa	VId
(3)	370	IIId	VIad
(4)	1,240	IId	IVds
(5)	240	IIIad	VIads
(6)	1,420	VIst	I
(7)	120	VIst	VIst
(8)	1,070	VIsd	IVsd
(9)	2,070	I	IId
(10)	510	IIa	IIIad
(11)	1,220	I	I

These locations are shown in Fig. C-4.

In this land classification, about 5,790 ha or 68% of the total area corresponds to arable land (classes I, II and III) suitable for rice cultivation, while 5,380 ha (or 63%) for upland farming as shown below.

Unit: ha

Land Classes	Scheme Area Kisiwani	Igoma	Gonja	Ndungu	Kihurio	Total Extent
A. Land to be suitable for Paddy cultivation						
I (9)+(11)	140	460	760	710	1,220	3,920
IIa (2)+(10)	-	140	230	250	30	650
IId (4)	250	-	470	250	270	1,240
IIId (3)	70	-	-	50	250	370
IIIad(5)	-	-	70	-	170	240
Total	460	600	1,530	1,260	1,940	5,790
B. Land to be suitable for upland crop cultivation						
I (6)+(11)	230	490	570	440	930	2,640
IId (9)	140	170	610	530	620	2,070
IIIs (1)	90	-	-	70	-	160
IIIad(10)	-	-	230	250	30	510
Total	460	660	1,390	1,290	1,580	5,380

Generally, this arable land of about 5,790 ha has a sufficiently high tillability and irrigability as well as sustainable surface drainability. The soil constraints, such as alkalinity and salinity could be improved and/or modified satisfactorily with a reasonable range of capitl investment. About 1,420 ha or 17% of the land, which is graded into class VI for paddy but class I for upland crops, is also considered as potential arable land. The total arable land to be taken for study is about 7,210 ha as shown below.

Unit: ha

Land Classes	Serial Soil No.	Scheme Area: Kisiwani	Igoma	Gonja	Ndungu	Kihurio	Total Extent
I	I (11)	-	290	150	180	600	1,220
I	II (9)	140	170	610	530	620	2,070
IIa	IIIad(10)	-	-	230	250	30	510
IIa	VId (2)	-	140	-	-	-	140
IId	IVds (4)	250	-	470	250	270	1,240
IIId	VIads (3)	70	-	-	50	250	370
IIIad	VIads (5)	-	-	70	-	170	240
Sub-total		460	600	1,530	1,260	1,940	5,790
VIst	I (6)	230	200	400	260	330	1,420
Total		690	800	1,930	1,520	2,270	7,210

Taking account of the above land classification, the project area is demarcated based on the present land use (See ANNEX C) and water for irrigation (See ANNEX G). The soils observed in the area are as follows:

Unit: ha

Soil Families (Soil No.)	Scheme: Kisiwani	Igoma	Gonja	Ndungu	Kihurio	Total	Land Classification: for Paddy	for Upland Crop
(1)	25	-	-	55	-	80	VIs	IIIs
(2)	-	140	-	-	-	140	IIa	VId
(3)	20	-	-	5	100	125	IIId	VIad
(4)	200	-	335	160	255	950	IId	IVds
(5)	-	-	40	-	145	185	IIIad	VIads
(6)	75	200	105	205	180	765	VIst	I
(7)	5	60	-	-	5	70	VIst	VIst
(8)	-	-	255	60	-	315	VIst	IVsd
(9)	95	70	340	475	570	1,650	I	IId
(10)	-	-	180	210	30	420	IIa	IIIad
(11)	-	290	105	170	595	1,160	I	I
Total:	420	860	1,360	1,340	1,880	5,860		

Based on the above land classification, demarcation of irrigable land to be taken for the project study is made as summarized below. About 3,230 ha are classified into suitable land for both rice and upland crop cultivation, about 1,400 ha are classified into suitable land for rice cultivation but marginally suitable for upland crop cultivation, 845 ha are classified into suitable or marginally suitable for upland crop cultivation but not suitable for rice cultivation and 385 ha is not suitable for both rice and upland crop cultivation.

Unit: ha

Soil Families No.	Area	Land Class: for Rice Cultivation	Land Class: for Upland Crop Cultivation	Land Utilization Types: Upland Field	Land Utilization Types: Paddy Field	Land Utilization Types: Upland /Paddy Field	Land Utilization Types: Exclussive Area
1	80	VIs	IIIs	80	-	-	-
2	140	IIa	VId	-	140	-	-
3	125	IIId	VIad	-	125	-	-
4	950	IId	IVds	-	950	-	-
5	185	IIIad	VIads	-	185	-	-
6	765	VIst	I	765	-	-	-
7	70	VIst	VIst	-	-	-	70
8	315	VIsd	IVsd	-	-	-	315
9	1,650	I	IId	-	-	1,650	-
10	420	IIa	IIIad	-	-	420	-
11	1,160	I	I	-	-	1,160	-
Total	5,860			845	1,400	3,230	385

Table C-1 SOIL CLASSES IN MKOMAZI VALLEY AREA

Soil Classes in Higher Category			Soil Classes in Lower Category		Mapping Sampling
Soil Order	Soil Sub-Order	Great Soil Group	Soil Sub-Group	Soil Family	
Entisots	- Fluvents	- Ustifluvents	- Typic Ustifluvents	- Sandy mineral soils	(1)
			- Mollic Ustifluvents	- Loamy, calcareous, low humic soils	(2)
			- Vertic Ustifluvents	- Clayey, calcareous, strong alkaline soils	(3)
	- Aquents	- Fluvaquents	- Mollic Fluvaquents	- Clayey, strong alkaline, low humic soils	(4)
				- Clayey, alkaline/ saline, low humic soils	(5)
	- Orthents	- Ustorthents	- Typic Ustorthents	- Alkaline soil	(6)
			- Lithic Ustorthents	- Sandy skeletal soils	(7)
	- Psamments	- Ustipsamments	- Typic Ustipsamments	- Alkaline soil	(8)
Inceptisols	- Aquepts	- Tropaquepts	- Typic Tropaquepts	- Clayey, alkaline soils	(9)
				- Clayey, alkaline/ saline soils	(10)
	- Tropepts	- Ustropepts	- Fluventic Ustropepts	- Clayey mineral soils	(11)

Table C-2 (1/2) CHEMICAL PROPERTIES OF MAJOR SOILS

Sample No.	Horizon Depth (cm)	pH (H_2O) (1:2.5)	ECe (m.mhos/cm/25°C)	Total Carbon (mg/g)	Total Nitrogen (%)	Water Soluble Salts (mg/100 g) Na	K	Ca	Mg	CO_3	Cl	SO_4
9-1	0-60	8.00	0.30	16.93	0.157	0.75	0.70	1.61	1.24	2.48	1.07	1.99
9-2	60-150+	8.00	0.49	4.83	0.06	1.96	1.49	5.23	1.36	13.02	1.36	4.08
10-1	0-30	8.05	9.50	15.79	0.055	106.18	1.14	20.05	9.11	5.58	59.02	221.14
10-1(S)	(0-2)	7.90	18.50	26.08	-	169.19	1.48	38.67	24.12	3.10	212.78	251.62
10-2	30-60	9.10	7.00	9.17	0.032	148.34	0.81	4.18	5.38	29.76	52.35	214.49
10-3	60-150+	9.00	7.60	5.29	0.026	95.63	0.44	8.84	9.82	16.12	45.82	225.84
20-1	0-25	9.50	54.00	10.33	0.115	855.69	6.75	51.38	32.99	9.30	806.30	980.22
20-2	25-40	10.00	33.00	11.18	0.036	696.23	2.29	10.03	8.88	13.64	588.54	792.24
20-3	40-150+	9.80	33.00	7.30	0.024	710.20	1.80	33.55	9.75	13.02	553.06	943.40
28-1	0-15	8.00	0.50	22.33	0.126	5.94	1.32	1.05	0.74	4.96	2.58	6.58
28-2	15-50	9.30	0.80	16.46	0.040	16.86	0.84	1.84	1.63	26.04	4.43	8.48
28-3	50-150+	9.50	1.30	7.31	0.020	1.11	2.90	4.70	2.01	20.46	1.32	2.53
36-1	0-25	9.10	0.34	28.05	0.117	4.58	0.80	2.80	0.97	30.38	2.75	26.34
36-2	25-100	9.20	0.85	19.03	0.074	3.68	0.28	5.11	2.64	22.94	2.47	9.13
36-3	100-150+	9.40	0.60	14.96	0.035	2.02	0.11	2.82	2.07	15.50	1.33	4.04

Table C-2 (2/2) CHEMICAL PROPERTIES OF MAJOR SOILS

Sample No.	Horizon Depth (cm)	Cation Exchange Capacity (m.eq/100 g)	Exchangeable Bases (m.eq/100 g) Na	K	Ca	Mg	Total Exchangeable Bases (m.eq/100 g)	Base Saturation Degree (%)	Exchangeable Sodium Percent
9-1	0-60	35.65	9.96	1.08	0.13	5.87	17.04	47.8	3.6
9-2	60-150+	27.09	15.70	0.75	0.19	2.57	19.21	70.9	7.0
10-1	0-30	32.58	16.65	1.01	8.39	10.21	36.26	111.3	25.8
10-1(S)	(0-2)	30.56	30.81	1.25	22.58	17.85	72.49	237.2	73.9
10-2	30-60	11.30	16.53	1.36	10.13	10.96	38.98	345.0	89.6
10-3	60-150+	28.98	18.03	0.75	4.91	6.98	30.67	105.8	16.9
20-1	0-25	17.52	8.77	1.20	25.25	5.59	40.81	232.9	144.1
20-2	25-40	15.59	2.60	0.57	32.94	2.01	38.12	244.5	211.3
20-3	40-150+	23.35	8.51	0.73	43.76	2.76	55.76	238.8	187.4
28-1	0-15	14.79	9.45	1.03	1.16	3.21	14.85	100.4	7.8
28-2	15-50	18.51	6.39	0.10	2.26	2.57	11.32	61.2	12.2
28-3	50-150+	28.15	13.36	0.87	7.20	6.04	27.47	97.6	25.6
36-1	0-25	34.20	18.57	3.19	0.08	6.39	28.23	82.5	2.3
36-2	25-100	39.71	17.81	0.92	0.59	12.56	31.88	80.3	1.5
36-3	100-150	6.05	7.05	0.17	0.29	5.18	12.69	209.8	4.8

Table C-3 (1/4) SALINITY AND ALKALINITY OF MAJOR SOILS

Sample No.	Horizon Sequences	Depth (cm)	Texture	Soil colour (When wet)	pH (1:2.5)	ECe (m.mhos/cm25°C)
1 - 1	Ap	0 - 30	CL	5YR 2/4	7.80	0.21
1 - 2	C	30 - 150'	CL	5YR 3/4	7.60	1.60
2 - 1	Ap	0 - 30	CL	10YR 2/2	7.80	0.16
2 - 2	C	30 - 90	CL	7.5YR 2/3	8.00	1.90
2 - 3	IIC	90 - 150'	LS	10YR 3/4	8.00	0.10
3 - 1	A	0 - 20	CL	5YR 2/2	7.80	0.14
3 - 2	C	20 - 45	SL	5YR 4/4	8.60	0.95
3 - 3	IIC	45 - 150'	f.GS	5YR 4/6	8.80	0.55
5 - 1	A	0 - 25	SiC	2.5YR 4/1	8.90	0.95
5 - 2	C	25 - 150'	fS x SiC	2.5YR 4/2	8.80	1.08
6 - 1	A	0 - 20	LS	7.5YR 3/3	7.80	0.17
6 - 2	C	20 - 35	S	7.5YR 3/4	8.00	0.08
6 - 3	IIC	35 - 150'	SiC	7.5YR 4/4	7.80	0.02
7 - 1	A	0 - 30	CL	7.5YR 3/3	7.20	0.27
-	C	30 - 40	S	7.5YR 4/3	-	-
7 - 2	C2	40 - 150'	SL	7.5YR 4/3	7.70	0.20
8 - 1	A	0 - 40	L	2.5YR 3/4	8.80	0.86
8 - 2	B	40 - 90	CL	2.5YR 4/4	9.00	6.13
8 - 3	C	90 - 200'	CL	2.5YR 4/6	9.10	7.50
9 - 1	A	0 - 60	CL	5YR 3/2	8.00	0.30
9 - 2	C	60 - 150'	C	5YR 3/4	8.00	0.49
10 - 1(s)	A(s)	0 - 2	CL	2.5YR 3/2	7.90	18.50
10 - 1	A	0 - 30	C1	2.5YR 3/2	8.05	9.50
10 - 2	C1	30 - 60	CL	2.5YR 3/4	9.10	7.00
10 - 3	C2	60 - 150'	SiCL	2.5YR 3/4	9.00	7.60
11 - 1	A	0 - 10	SiC	10YR 3/2	8.80	5.00
11 - 2	C	10 - 50	CL	10YR 5/2	8.40	1.53
11 - 3	C2	50 - 150'	CL	10YR 5/4	8.80	0.72
12 - 1	A	0 - 30	C	5YR 3/3	8.50	3.50
12 - 2	B	30 - 110	C	5YR 4/3	8.60	6.75
12 - 3	C	110 - 160'	C	5YR 4/6	8.80	6.50
13 - 1	A	0 - 15	LS	5YR 4/4	9.40	0.21
13 - 2	B	15 - 55	L	5YR 4/3	9.60	0.18
13 - 3	C	55 - 70	G.LS	7.5YR 6/6	9.20	0.19
13 - 4	IIC	70 - 85	LS	7.5YR 6/6	9.20	0.23
13 - 5	IIIC	85 - 100	f.G	7.5YR 6/6	9.10	0.12
13 - 6	IVC	100 - 200'	fSL	5YR 6/6	9.00	0.57

Table C-3 (2/4) SALINITY AND ALKALINITY OF MAJOR SOILS

Sample No.	Horizon Sequences	Depth (cm)	Texture	Soil colour (When wet)	pH (1:2.5)	ECe (m.mhos/cm25°C)
14 - 1	A	0 - 20	L	5YR 4/4	9.20	0.31
14 - 2	B	20 - 50	CL	5YR 4/6	9.70	0.11
14 - 3	C	50 - 60	fG.SL	5YR 4/6	9.20	0.27
14 - 4	IIC	60 - 150'	L	5YR 5/6	9.60	0.19
15 - 1	A	0 - 20	CL	5YR 4/3	9.40	0.19
15 - 2	B	20 - 60	C	5YR 4/6	9.10	3.00
15 - 3	C	60 - 130	L	5YR 5/6	9.00	9.25
15 - 4	IIC	130 - 150'	G.L	5YR 5/6	9.00	11.80
16 - 1	A	0 - 20	fL	7.5YR 3/2	10.00	0.90
16 - 2	C	20 - 70	CL	5YR 4/4	9.00	1.77
16 - 3	IIC	70 - 100'	G.CL	5YR 4/5	9.60	1.20
17 - 1	A	0 - 20	CL	7.5YR 4/3	9.10	0.78
17 - 2	B	20 - 70	CL	5YR 5/6	8.70	1.77
17 - 3	C1	70 - 100	L	5YR 5/6	9.50	0.50
17 - 4	C2	100 - 130	S.CL	5YR 6/6	9.50	0.30
17 - 5	C3	130 - 150'	LC	5YR 6/6	9.60	0.29
18 - 1	A	0 - 20	C	5YR 3/3	9.00	2.00
18 - 2	B	20 - 70	C	5YR 3/6	9.10	0.47
18 - 3	C	70 - 150'	C	5YR 4/6	9.40	0.53
19 - 1	A	0 - 20	C	5YR 3/3	7.70	6.25
19 - 2	B	20 - 50	C	2.5YR 3/4	8.80	1.90
19 - 3	C	50 - 150'	C	2.5YR 3/6	9.00	1.70
20 - 1	A	0 - 25	C	2.5YR 3/4	9.50	54.00
20 - 2	B	25 - 40	SC	2.5YR 4/4	10.00	33.00
20 - 3	C	40 - 150'	CL	5YR 3/6	9.80	33.00
21 - 1	A	0 - 20	CL	2.5YR 3/3	9.40	0.10
21 - 2	AB	20 - 75	CL	2.5YR 4/6	9.30	3.35
21 - 3	B	75 - 150'	C	2.5YR 3/4	9.00	4.75
22 - 1	A	0 - 15	CL	5YR 4/6	9.40	0.40
22 - 2	AB	15 - 80	LS	5YR 4/8	9.40	0.45
22 - 3	B	80 - 150'	C	2.5YR 4/6	8.60	0.36
23 - 1	A	0 - 30	L	2.5YR 3/6	8.50	1.75
23 - 2	B	30 - 90	L	2.5YR 4/6	8.80	6.25
-	C	90 - 150'	L	2.5YR 5/8	-	-
24 - 1	A	0 - 20	L	2.5YR 4/6	9.30	0.25
24 - 2	B	20 - 50	SC	2.5YR 3/4	9.10	0.31
24 - 3	C	50 - 150'	L	2.5YR 4/6	10.00	0.68

Table C-3 (3/4) SALINITY AND ALKALINITY OF MAJOR SOILS

Sample No.	Horizon Sequences	Depth (cm)	Texture	Soil colour (When wet)	pH (1:2.5)	ECe (m.mhos/cm/25°C)
25 - 1	A	0 - 30	CL	2.5YR 4/3	9.00	0.28
25 - 2	B	30 - 70	CL	2.5YR 3/4	9.30	0.50
25 - 3	C1	70 - 110	CL	2.5YR 4/6	9.50	3.12
25 - 4	C2	110 - 150'	CL	5YR 4/4	8.90	7.50
26 - 1	A	0 - 30	CL	7.5YR 3/4	8.50	1.03
26 - 2	C1	30 - 60	CL	7.5YR 3/4	10.20	0.80
26 - 3	C2	60 - 150'	CL	7.5YR 3/6	9.10	11.80
27 - 1	A	0 - 20	CL	7.5YR 3/3	9.30	0.56
27 - 2	C	20 - 50	CL	5YR 4/4	8.50	0.50
-	IIC	50 - 60	S	5YR 4/6	-	-
27 - 3	IIIC	60 - 150'	CL	5YR 4/6	8.20	0.07
28 - 1	A	0 - 15	CL	7.5YR 4/2	8.00	0.50
28 - 2	C1	15 - 50	SC	7.5YR 4/4	9.30	0.80
28 - 3	C2	50 - 150'	SC	7.5YR 4/6	9.50	1.30
30 - 1	A	0 - 20	CL	7.5YR 3/3	8.80	1.65
30 - 2	C	20 - 40	S	7.5YR 3/6	8.20	0.08
30 - 3	IIC	40 - 150'	L	7.5YR 4/4	7.50	0.85
31 - 1	A	0 - 20	C	7.5YR 3/2	7.90	0.93
31 - 2	C	20 - 150'	CL	7.5YR 4/4	8.30	2.07
33 - 1	A	0 - 20	CL	7.5YR 3/4	6.10	0.12
33 - 2	B	20 - 50	C	7.5YR 4/4	7.40	0.17
33 - 3	C	50 - 150'	L	7.5YR 4/8	7.80	0.50
34 - 1	A	0 - 30	CL	7.5YR 3/4	7.40	0.27
34 - 2	C	30 - 60	CL	7.5YR 4/4	7.30	0.20
-	IIC	60 - 150	S	7.5YR 5/4	-	-
35 - 1	A	0 - 30	L	2.5YR 2/4	8.40	0.22
35 - 2	B	30 - 80	CL	2.5YR 3/6	8.60	0.30
35 - 3	C	80 - 150'	L	2.5YR 4/6	9.10	0.35
36 - 1	A	0 - 25	C	5YR 3/1	9.10	0.34
36 - 2	C	25 - 100	C	5YR 4/3	9.20	0.85
36 - 3	IIC	100 - 150'	CL	5YR 6/2	9.40	0.60
37 - 1	A	0 - 45	C	5YR 3/1	9.40	0.57
37 - 2	C	45 - 140	C	5YR 3/2	9.70	0.73
38 - 1	A	0 - 20	C	10YR 3/3	8.70	0.27
38 - 2	AB	20 - 100'	C	10YR 3/4	8.90	0.63

Table C-3 (4/4) SALINITY AND ALKALINITY OF MAJOR SOILS

Sample No.	Horizon Sequences	Depth (cm)	Texture	Soil colour (When wet)	pH (1:2.5)	ECe (m.mhos/cm/25°C)
39 - 1	A	0 - 5	L	7.5YR 3/3	9.20	0.35
39 - 2	C	5 - 20	S	7.5YR 4/4	9.50	0.26
39 - 3	IIC	20 - 25	C	7.5YR 4/4	9.00	0.55
39 - 4	IIIC	25 - 100	S	10YR 4/4	9.10	0.30
-	IVC	100 - 150'	C	7.5YR 3/3	-	-
40 - 1	A	0 - 50	C	7.5YR 3/3	7.60	0.55
40 - 2	B	50 - 150'	C	7.5YR 4/6	7.40	0.40
41 - 1	A	0 - 30	C	7.5YR 3/4	7.70	1.26
41 - 2	C	30 - 150	C	7.5YR 4/6	7.80	0.30

(Note: All the figures are obtained by field investigation and testing through the present soil survey work.)

Table C-4 CRITELIA FOR RATING OF LAND FACTORS

1. Soil Conditions

1.1 Soil Testure Qualities

	Surface Soils	Sub-surface Soils
s0:	Coarse loamy to fine loam	Fine loamy to fine clay
s1:	Fine loamy to fine clay	Coarse loamy to fine clay
s2:	Coarse loamy and/or very fine clayey	Coarse loamy and/or very fine clayey
s3:	Sandy and/or histic soils	Sandy and/or histic soils

1.2 Effective Soil Depth

Depth to sand, gravel, cobble, plinthite, mud-clay or histics

k0: Very deep - more than 90 cm
k1: Deep - 50 to 90 cm
k2: Moderate - 20 to 50 cm
k3: Shallow - less than 20 cm

Depth to impermeable layer for Diversified Crops		for Paddy Rice	
i0:	Very deep - more than 150 cm	k0:	Very deep - more than 90 cm
i1:	Deep - 120 to 150 cm	k1:	Deep - 50 to 90 cm
i2:	Moderate - 100 to 120 cm	k2:	Moderate - 20 to 50 cm
i3:	Shallow - less than 100 cm	k3:	Shallow - less than 20 cm

1.3 Soil Acidity (pH: H_2O 1:1 soil-water suspension)

a0: Silightly alkaline to neutral - 6.1 to 7.5
a1: Moderately strong alkaline - 2.6 to 8.5
a2: Strong alkaline - 8.6 to 9.0
a3: Very strong alkaline - 9.1 to 9.5
a4: Extremely strong alkaline - more than 9.5

2. Topography

2.1 Relief Conditions

r0: Flat to nearly flat
r1: Gently sloped land
r2: Undulating
r3: Rolling

2.2 Sloping Conditions

t0: 0 to 2%
t1: 2 to 5% in single slope
t2: 5 to 8% in single slope
t3: 8 to 15%
t4: more than 15%

3. Drainage Conditions

3.1 Soil Drainability

d0: Well drainable
d1: Moderately drainable
d2: Somewhat poorly drainable
d3: Poorly drainable
d4: Very poorly drainable

3.2 Seasonal Flooding

f0: Non seasonal flooding (non inundation)
f1: Seasonal flooding shallowly (sometime inundated)
f2: Seasonal flooding deeply (frequently inundated)
f3: Flooding throughout the year (inundated all the times)

Source: Irrigation suitability classification, US Bureau of Reclamation, 1967

Table C-5 TERMS OF LAND CLASSIFICATION AND THEIR SPECIFIC DEGREE

Suitability	Suitable				Unsuitable
Specific Degree	Very High (1)	High (2)	Moderately High (3)	Low (4)	Very Low (5)
Soil and land Qualities					
1. Soil fertilities					
- organic carbon (%)	more than 0.75	more than 0.75	0.15 to 0.75	less than 0.15	less than 0.15
- total nitrogen (%)	more than 0.05	more than 0.05	0.01 to 0.05	less than 0.01	less than 0.01
- available P_2O_5	high	moderate	low	very low	very low
- C.E.C (m.eq.)	more than 10	more than 10	3 to 10	less than 3	less than 3
- potassium (m.eq.)	more than 0.2	more than 0.2	0.1 to 0.2	less than 0.1	less than 0.1
- base saturation (%)	more than 40	more than 40	10 to 40	less than 10	less than 10
2. Alkalinity of soils (pH: 1:2.5 soil-water suspension)					
	less than 8.5	less than 8.5	8.5 to 9.0	more than 9.1	more than 9.5
3. Soil Depth (cm)					
- depth to sand, etc.	more than 90	more than 90	50 to 90	20 to 50	less than 20
- depth to impermeable layer	more than 150	120 to 150	120 to 150	100 to 120	less than 100
4. Topography					
- relief	flat to nearly flat	flat to nearly flat	gently sloped	undulating	rolling
- slope (%)	0 to 2	2 to 5	5 to 8	8 to 15	more than 15
5. Drainage Conditions					
- drainability	well	moderate	somewhat poor	poor	very poor
- seasonal flooding	non flooding	non flooding	short and shallowly flooded	long and deeply flooded	permanently and deeply flooded
Land Capability					
6. Conditions for seeding establishment and tillability					
- soil structure	structureless & granular	sub-angular block	sub-angular blocky	blocky to massive	massive
- consistence	friable	friable	firm	very firm	extremely firm
- susceptibility to surface sealing	slight	slight	moderate	strong	strong
7. Workability					
- consistence when wet	non to slightly sticky & plastic	slightly sticky & plastic	sticky & plastic	very sticky & very plastic	very sticky & very plastic
- consistence when dry	loose to moderate	moderately hard	moderately hard to hard	very hard	very hard to extremely hard
8. Possibility for farm mechanization					
- land form & slope	flat to gently sloped	gently undurating	undulating	rolling	rolling and steeply sloped
9. Capability for maintaining surface water					
- permeability	less than 1.4×10^{-4} cm/sec.	1.3 to 5.5 x 10^{-4} cm/sec.	1.6×10^{-3} to 5.5×10^{-4} cm/sec.	less than 1.6×10^{-3} cm/sec.	less than 1.6×10^{-3} cm/sec.

Note: Sources: Land suitability classification for irrigated paddy and diversified crops defined by U.S. Bureau of Reclamation, 1967.

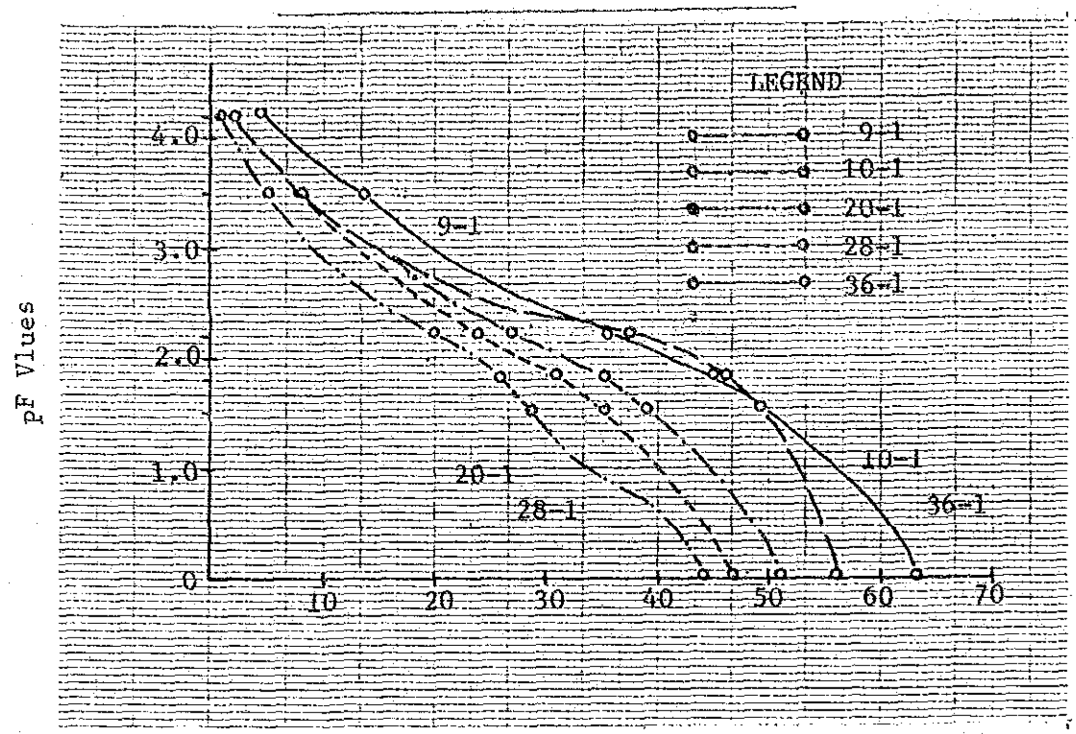
Criteria for land capability appraisal is preliminarily estimated based on the specific degree generally accepted.

Table C-6 SUMMARY OF LAND CLASSIFICATION

(LAND SUTABILITY APPRAISAL OF MAJOR SOIL AREA)

Soil Sub-Group	Soil Family	Serial Soil No.	Appraisal in Suitability Classes	
			For Rice	For Upland Crops
Typic Ustifluvents	Sandy mineral soils	(1)	VIs	IIIs
Mollic Ustifluvents	Fine loamy, calcareous and low humic soils	(2)	VIs	IIs
Vertic Ustifluvents	Clayey, calcareous, and strong alkaline soils	(3)	IIId	VIad
Mollic Fluvaquents	Clayey, strong alkaline and low humic soils	(4)	IId	IVds
	Clayey, strong alkaline/saline and low humic soils	(5)	IIIad	VIads
Typic Ustorthents	Loamy, strong alkaline soils associated with sandy and clayey soils	(6)	VIst	I
Lithic Ustorthents	Sandy skeletal mineral soils including out-crops	(7)	VIst	VIst
Typic Ustipsamments	Alkaline and mineral soils	(8)	VIsd	IVsd
Typic Tropaquents	Clayey and moderately strong alkaline soils	(9)	I	IId
	Clayey and moderately strong alkaline/saline soils	(10)	IIa	IIIad
Fluventic Ustropepts	Clayey mineral soils	(11)	I	I

pF CURVE OF MAJOR SURFACE SOILS



Moisture (Volume %)

Unit: volume %

Sample No.	pF Value					
	0	1.5	1.8	2.2	3.5	4.2
9-1	51.05	39.10	35.00	27.15	7.20	3.05
10-1	56.10	49.25	46.55	37.30	7.25	3.05
20-1	43.50	28.70	26.00	20.05	6.80	1.70
28-1	46.20	35.05	31.80	23.95	7.25	3.00
36-1	63.05	49.30	44.50	34.10	13.75	4.85

Fig. C-1 pF CURVES OF MAJOR SOILS