ANNEX - C

GEOLOGICAL INVESTIGATION

ANNEX-C GEOLOGY AND CONSTRUCTION MATERIALS

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C1 Geology

C1.1 Regional Geology

The Tana river rises from the Aberdare Range (Mt. Ol-doinyo Lesatima; EL. 3,999 m) which is located at about 80 km west of Mt. Kenya (EL. 5199 m). In the upper and middle reaches of the river, many tributaries which show radial drainage pattern join from the slopes of Mt. Kenya.

Tana river basin can be divided into three distinct physiographic units from west to east, the eastern slopes of Aberdare Range and the southern - eastern slopes of Mt. Kenya, the Kenya Basement System terrain (peneplain) and Tertiary - Quaternary sediments area.

The eastern slopes of Aberdare Range and the southern - eastern slopes of Mt. Kenya are formed by the volcanic formations which overlie the basement complex formations (Kenya Basement System). The volcanic formations are composed of basalt, phonolite, agglomerate, tuff, etc., originates from Mt. Kenya and the Aberdare Range.

The volcanic activity (eruption) of Mt. Kenya is estimated to be in the late Tertiary (Miocene-Pliocene) to early Quaternary (Pleistocene) age, and no evidence of volcanic activity is found in the Recent (Holocene).

The middle reach of the Tana river runs on the Kenya Basement System terrain which is composed mainly of high-grade gneisses of the Kenya Basement System of the Archaean age. Several types of intrusive rock (mainly granite) are found in the gneisses.

The lower reach of the Tana river flows on the rather flat plain formed by the sedimentary rock or sediment layers of Tertiary to Quaternary age. The river forms the flood plains along the course which comprises river levee land and river basin land. The river levee land lies just above the normal flood level and is generally flat. The river basin land is seen in the outside of the levees, is periodically flooded. The Tana river forms the delta (recent deposits) at the outlet to the Indian ocean. In the delta, the Tana river has periodically changed its course.

C1.2 Reservoir Geology

The reservoir areas of the Mutonga and Grand falls dams are located in the middle reach of the Tana river. The geology of both reservoir areas is composed of high-grade gneisses of the Kenya Basement System of Archaean age. The gneisses (metamorphic rock) show a wide variety of rock facises in the area, reflecting the varied nature of the original sediments from which the gneisses were derived. They range from granite gneiss through semi-pelitic banded gneiss to biotite-rich pelitic-mafic, semi-felsitic and hornblende plagioclase gneisses.

There are two prominent ridges (monadnock); (a) Kijege forest - Kierera forest (N-S direction) and (b) Gikingo forest - Mutejwa forest - Kamuwongu - Kiuga - Mumoni forest (NNE-SSW direction), formed by mainly granitic gneiss which have rather higher resistance to weathering than the other gneisses. The Tana river runs in the area between those two ridges from south to north until Grand Falls. In the downstream from the Grand Falls, the river course changes toward the east and cuts the later ridge (b). The area between two ridges is formed mainly by semi-pelitic banded gneisses, biotite rich pelitic - mafic gneiss, etc. poorly resistant to weathering. (Refer to Figure C1.2.1.)

The river courses of the Tana river and other tributaries are generally adapted by the slopes of Mt. Kenya and structures of the Kenya Basement System, mainly strike of the gneisses formation which shows between north and northeast direction over the reservoir areas.

The gneisses have been intruded by many small and several large granite bodies, generally fine-grained and partly coarse or pegmatitic.

Basalt lava flow, originating from Mt. Kenya, of Tertiary or even younger age, develops on a long narrow ridge about 1.5 km north of the Mutonga damsite. The lava flow is found more than 130 m above river level and no other outcrops can be seen at lower elevation.

Overburden in the reservoir areas consists of a thin covering of residual soil which is mainly sandy gravels, silty sand, silty clay or clayey silt. Sandy deposits are seen in some seasonal rivers, such as Kalange, Kamura, Konyu, etc.

No noticeable fault structures are found in the reservoir areas.

C1.3 Geology in the Project Areas

C1.3.1 Mutonga Project

(1) Introduction

The Mutonga project site is located approximately 37 km downstream from the Kiambere site. The geology consists of gneisses of the Kenya Basement System and some granitic intrusions.

The geological investigation as a feasibility study has been carried out in the 1979/1980 period by the British consulting firm, Engineering and Power Development Consultants (EPDC), as part of their work on the Kiambere Feasibility Study, and some additional geological mapping has been done in the 1986/1987 period by UNDP/World Bank/Acres. The investigation results are described in the following reports respectively.

(a) Kiambere Hydroelectric Development Feasibility Study
Geology Report, Part 3(A), April 1980
Tana River Development Company Ltd, Kenya/EPDC

Geological mapping: scale 1/5,000 approximately.
Seismic survey: 10 spreads, about 3.2 km in total

Table: Boring Investigation

Hole No.	Depth (m)	Lugeon test (nos)	Location
MDD-1	35.22	4	Right bank
MDD-2	35.22	4	Right bank
MDD-3	25.28	4	Right bank
MDDS-4	25.00	0	Spillway weir
Total	120.72	12	

Source: EPDC Report 1980

(b) Kenya National Power Development Plan, 1986 - 2010
Appendix Vol. 2, June 1987
UNDP/World Bank/Acres

Geological mapping: scale 1/5,000 approximately.

The geological investigation in this study (1995) is the additional study for the above as the feasibility study stage. The dam axis in this stage was selected at about 50m downstream from the original axis proposed in the above mentioned studies.

Investigation item and quantity in this study (1995) are summarised in Table C1.3.1, and each location of bore holes and seismic survey lines are shown in Figure C1.3.1.

(2) Geology of damsite area

The overburden consists of a thin covering of residual soil which is sandy gravel, gravely sand, silty clay or clayey silt, and alluvium deposits. Alluvial deposits consist of sand with frequent gravel, cobbles and, sometimes boulders exist along the banks of the Tana river and in the river beds of some of the seasonal rivers surrounding the dam site area.

Bedrock belong to the Archaean Kenya Basement System consists of mafic - semi-felsitic and granitic gneisses which have been intruded by small contemporary bodies of granite and pegmatite. The mafic gneiss, comprising with thin, closely spaced bands of biotite, hornblende, quartzo-feldspathic materials, etc. is the dominant rock type in the area. Younger sedimentary rock (sandstone, limestone, etc.) is seen in some areas narrowly/thin and indiscontinuously.

Generally the mafic gneiss is more highly weathered and weaker than the semi-felsitic gneiss and granitic gneiss. Results from the drilling investigation, the bedrock is typically weathered to a depth of several meters to 15 m in maximum approximately.

The gneisses have a foliation of N20-40°E/60-80°NW in general. Major joint structures also are of a generally similar direction and dip of the foliation. Minor joint structures are N40-60°W/70-85°NE-SW on the outcrops distributed along both banks of the Tana river.

No major fault structures were identified in the dam site area. Some minor crushed and sheared zones were observed on the rock outcrops on both banks of the Tana river and of the seasonal river located at right bank, immediately downstream of the dam site. One fault is reported in previous investigation reports to exist approximately 1 km south-southeast of the dam site (which could not be confirmed in this study, 1995).

(3) Geology of dam foundation

The main dam is proposed to be a center core type zoned rock fill dam with a height of approximately 47m and a crest length of approximately 660m or concrete gravity dam. Spillway in the case of the rock fill dam is proposed to be located about 200m away from dam body to the north.

The right and left river bank slopes for about a 10m height from the river level are very steep, 40 - 60 degrees in general. The upper half of the left bank slope is rather gentle, 20 - 30 degrees, where gneisses (highly to moderately weathered) are rarely outcropped. The right bank is formed by gently sloped hills with fewer outcrops of rocks than that in the left bank. Moderately - slightly weathered to fresh, and hard gneisses are seen along both banks in the Tana river channel. River bed deposit is distributed in the right bank narrowly, formed by sand, silty sand, gravels and boulders, seems to be rather thin, several meters in maximum thickness.

The foundation rocks are mostly well foliated mafic gneiss, with some semi-felsitic gneiss and granitic gneiss, having the following joints in general.

Table: Major Joint Structure

Strike/dip	
N20-40°E/60-80°NW:	Along foliation, several 10cm to 1m intervals approx.
N40-60°E/70-80°NE-SW:	Along river flow direction, several meters interval.

Source: JICA Study Team

The geological map is shown in Figure C1.3.1 and geological profiles are shown in Figure C1.3.3 and Figure C1.1 to C1.6 in Annex-C.

(a) Excavation line for dam core zone trench

The bed rock is generally deeply weathered. According to the drilling results along the dam axis, the weathering condition is summarised in Table C1.3.2. From the results of drilling, the depth of slightly weathered rock surface in both abutments observed in the investigation boreholes is estimated to be as follows.

Table: Rock Classification

Prvious dam axis (1979/1980)

Depth of moderately - slightly weathered rock surface (m)		
Left abutment	3.50	(MDD-1)
Right abutment	15.20 - 5.50	(MDD2 & MDD3)

Source: EPDC Report 1980

Dam axis in this stage (1995)

Depth of moderately-slightly weathered rock (CM-CH class rock) surface (m)		
Left abutment	3.20 - 9.35	(M95-1 & M95-2)
River bed	3.00	(M95-3)
Right abutment	5.20 - 4.70	(95-4 & M95-5)

Source: JICA Study Team

The dam axis in this study is selected at about 50m downstream of the previous dam axis.

Moderately to slightly weathered rock (CM - CH) which approximately corresponds to the zones of seismic velocity more than 2.8km/s, will be appropriate for the foundation of the core zone of the center core type zoned rock fill dam and for the foundation of concrete gravity fill dam. Therefore, 3 to 5 m, partly about a 10 m deep excavation for the both abutments will be required in principle for the newly selected dam site in this study (1995). The river bed deposit which is formed by sand, silty sand, gravel and boulder is 3m thick at the bore hole M95-3. Rock shows CH class immediately below the river bed deposit.

The seismic survey was performed for the newly selected dam axes in 1995. The results are shown in Table C1.3.3 and in the geological profiles in Figure C1.3.4 and Figure C1.1 to C1.6 presented in Annex-C. The relation between seismic velocity (Vp) and rock classification is mentioned in Table C1.3.3.

The surface depth of the zones which have seismic velocity of more than 2.8-3.0 km/sec (CM-CH-B class rocks) on the dam axis is approximately as follows.

Table: Surface Burden Depth

DA-DB-DC (upstream)	Line	Depth of more than 2.8-3.0 km/sec (m)
Left abutment	M95-A	10 - 12m
Right abutment	M95-B	10 -13m

Source: JICA Study Team (Depth: approximately)

The relation between seismic velocity (Vp) and rock classification is mentioned in the later sub-clause (b) of the succeeding clause C1.3.2 (3).

Some low velocity zones are found in the seismic survey results as mentioned in Table C1.3.3 and in the geological profiles. These may suggest the existence of fault structures which have some fractured zones. However, the fractured zones of these fault structures observed in the field and in the drilling core samples show mostly re-consolidated and hard/in good condition, without any thick clayey zones, in general, while they have more joints and are sometimes more friable than normal rock.

The rocks, except decomposed soft rock, and river sand/gravel deposit will be appropriate for the shell zone foundation of rock fill dam in principle.

(b) Rock properties of foundation rock

The rocks at the Mutonga dam site are the same type of gneisses in the same formations of the Kenyan Basement System as the rocks in the Grand Falls dam site. Therefore, the rocks in this dam site may have similar properties to that of the Grand Falls dam site. (Refer to cluse C1.3.2(3))

(c) Permeability of foundation rock

The permeability test results in each borehole are summarised in Table C1.3.4.

High pervious rock, more than 10 Lugeon or coefficient of permeability of more than 1.0×10^{-4} cm/sec is seen in the following depth in the both abutments.

Left abutment	between rock surface and 10.00 - 10.30 - 13.20m deep. (MDD1, M95-2 & M95-1)
River bed	between rock surface and 5.50m deep. (M95-3)
Right abutment	between rock surface and 7.70 - 20.00 - 20.05 - 24.00m deep (M95-4, MDD3, M95-5 & MDD2)

The zones below the depth show very low permeability, being almost impermeable.

(d) Groundwater condition

According to the results of investigation performed by EPDC (1979), the groundwater level is estimated to be higher than the river water level in both banks.

The water levels measured during and after the drilling works in the boreholes are shown in the Supporting Report. The deepest water levels in the records of each borehole are summarised as follows.

Table: Ground Water Level

Hole No.	EL. of hole mouth (m)	Depth & (EL.) of water level (m)	Location
M95-1	554.60	25.95 (528.65)	Left bank
M95-2	537.59	9.75 (527.84)	Left bank
M95-3	512.98	0.90 (512.08)	River bed
M95-4	535.84	19.65 (516.19)	Left bank
M95-5	549.15	15.70 (533.45)	Left bank
M95-6	553.49	21.00 (532.49)	Spillway weir
M95-7	553.35	6.20 (547.15)	Spillway chute

Source: JICA Study Team (The deepest water level observed in each hole)

The bore hole M95-3 is located at the Tana river bed. Therefore, the water level measured in the M95-3 shows the water level of the Tana river at the dam site. All the records suggest that the groundwater levels in both abutments are higher than the Tana river water level, and rises toward the mountain sides in both banks.

(4) Foundation treatment of dam

The following grouting works will be required for the dam foundation

<u>For rock fill dam</u>

a. Curtain grouting;	Along the dam axis and spillway weir axis. Two lines, 2 - 3m hole spacing.
b. Blanket grouting;	For all the foundation area of impervious core zone. Depth of 5m, with 3m grid.

<u>For concrete gravity dam</u>

a. Curtain grouting;	Along the dam axis. Two lines, 2 - 3m hole spacing.
b. Consolidation grouting;	For all the dam foundation area. Depth of 5m, with 3m grid.

The curtain grouting hole depth will be 10 to 30m in general, considering to the permeability condition of the foundation rocks.

(5) Geology on other structures

(a) Diversion tunnel

The geological conditions at either right bank or left bank accepts diversion tunnel alignment. The tunnel length will be 500 - 600m approximately. Rocks along the proposed tunnel are expected to be mainly mafic gneiss with good quality in general in both banks. No major fault structure was observed in those areas, but minor shearing zones are anticipated. Highly to moderately weathered zones exist at the inlet and outlet portions in which rather dense tunnel support works will be required.

A seismic survey (lines M95-C and D) was performed for the possible tunnel routes on both banks in 1995. The results are shown in Table C1.3.3 and in the geological profiles presented in the Annex-C. The results show that the diversion tunnel route will be mostly in the area where the rocks show the seismic velocity of more than 3 km/sec and the rock classification of CM-CH-B.

(b) Spillway

In the case of the rock fill dam, a spillway is proposed to be in the left bank, behind the left abutment hill of the dam. The foundation rock is estimated to be mafic gneiss and some granite intrusions which are in appropriate condition as the spillway foundation. The area has no thick overburden layer.

Three numbers of investigation bore holes have been drilled till now. According to those drilling results, the weathering condition of the area is summarised below:

Table: Rock Weathering Conditions

Hole No.	Depth (m)	Weathering condition (Rock classification)
MDD4	0.00 - 19.00	Rs & highly to moderately weathered
	19.00 - 25.00	moderately-slightly, partly highly weathered
M95-6	0.00 - 14.35	Rs & highly to moderately weathered (D-CM)
	14.35 - 30.00	slightly weathered (CM-CH)
M95-7	0.00 - 7.50	Rs & highly to slightly weathered (D-CL)
	7.50 - 10.10	slightly weathered (CL-CH)

Source: EPDC Report 1980 and JICA Study Team

(Rs: Residual soil, Rd: River bed deposit)

MDD4 and M95-6 are located at the proposed spillway weir site. Weathering in confirmed to be as very deep as 14.35 to 19.00m in this area. For the construction of the weir, such deep excavation will be required. M95-7 is located at the higher part of the spillway chute, in which weathering is 7.50m.

The seismic survey (lines M95-E and F) was performed for the proposed spillway weir site and chuteway in 1995. The results are shown in Table C1.3.3 and in the geological profiles in Figures C1.1 to C1.6 in the Annex-C.

The results show that the zones which have a seismic velocity of more than 3 km/sec (CM-CH-B class rocks) are seen in the area deeper than 10 - 25m in the weir section (M95-E) and 10 - 20m in the chuteway section (M95-F). Therefore, deep excavation for the weir construction will be required, as mentioned in the former drilling investigation results.

The Lugeon test was done in the M95-6. The results are as follows.

Table: Lugeon Test Results

Hole No.	Depth (m)	Lugeon values
M95-6	0.00 - 4.00	no data
	4.00 - 9.80	0.4
	9.80 - 13.50	no data
	13.50 - 20.00	13.7
	20.00 - 30.00	0.1-1.9

Source: JICA Study Team

The following foundation treatment will be required for the construction of the spillway weir.

a. Curtain grouting; Along the weir axis, depth of 10 - 25m. One line, 2 - 3m hole spacing.

b. Consolidation grouting; For all the weir foundation area, depth of 5m, with 3m grid.

(c) Power house and intake structure

Both banks of the Tana river will be geologically appropriate for the construction of the power house. According to the previous design, the site is located in the right bank and the required maximum excavation depth is about 25 m. As the power house location will be close to the river, it is anticipated that the surface zones of highly weathered rocks will be thin and the excavation will be in good quality rocks in general.

An intake tunnel with the length of 300-500m will be required from the dam reservoir to the power house. The tunnel elevation will be higher than that of the diversion tunnel, therefore, more tunnel support works will be required than those of the diversion tunnel, because the tunnel will penetrate through shallow rock zones where foundation rock is weathered.

C1.3.2 Grand Falls Project

(1) Introduction

The Grand Falls project site is located approximately 25 km downstream from the Mutonga project site. The geology consists of gneisses of the Kenya Basement System and some granitic intrusions.

The geological investigation as a pre-feasibility study was carried out in the 1979/1980 by the British consulting firm, Engineering and Power Development Consultants (EPDC), as part of their investigation works on the Kiambere Feasibility Study, and additional geological investigation at a feasibility study level was done in 1986/1987 by the UNDP/World Bank/Acres. The investigation results are described in the following reports respectively.

(a) Kiambere Feasibility Study, April 1980, EPDC

Seismic survey: 14 spreads, 5.7 km in total
The investigation results are explained in the following report;
Kiambere Hydroelectric Development Feasibility Study
Geology Report, Part 3(B), April 1980
Tana River Development Company Ltd, Kenya/EPDC

(b) Kenya National Power Development Plan, 1986-2010, June 1987, UNDP/World Bank/Acres

The investigation results are explained in the following report;
Kenya National Power Development Plan, 1986 - 2010
Appendix Vol. 2, June 1987
UNDP/World Bank

Table: Boring investigation (with Lugeon tests)

Hole No.	Depth (m)	Location
BH-1	30.25	Right bank
BH-2	25.45	"
BH-3	40.45	"
BH-4	23.25	"
BH-5	19.00	Left bank
BH-6	10.05	"
BH-7	15.50	"
Total	163.95	

Source: Acres Report 1987

Geological mapping: scale 1/6,660 approximately.

The geological investigation in this study (1995) is the additional study for the above as the feasibility study stage. Investigation items and quantities in this study are summarised in Table 3.3.5, and each location of bore holes and seismic survey lines are shown in Figure C1.3.2.

The proposed dam is a zoned type rock fill dam. Alternative dam types will be a combine type dam of a rock fill dam (right bank section) and a concrete gravity dam (river channel section). There are two alternatives on dam height, which are about an 80m of Low Grand Falls dam and about a 120m of High Grand Falls dam. The investigation in this study (1995) was made on the Low Grand Falls dam.

Three alternative dam axis as the Low Grand Falls dam, "line A-D-B" (upstream), "line C-D-B" (midstream) and "line E-F-G" (downstream), were selected in this study as shown in the geological map in Figure. The alternative "line A-B" is almost the same location as the High Grand Falls dam axis. The alternative "line C-D-B" is the same location as the Low Grand Falls dam axis planned in the previous study. The alternative "line E-F-G" is newly selected in this study.

(2) Geology of damsite area

The overburden in the dam site area consists of mainly residual soil which is a generally thin layer of 1-2m in thickness, formed by silty to sandy soil with variable amounts of gravel, boulder and rock fragments. Alluvial deposits consisting of sand with frequent gravel, cobbles and, sometimes boulders, are found in relatively small quantities with narrow area along the Tana river and in the river beds of small seasonal rivers surrounding the damsite area.

Bedrock is Archaean metamorphic gneisses of the Kenyan Basement System. Some intrusions of granitic rock is seen in the gneisses. The main rock types are mafic gneisses, black to dark grey colored, comprising thin, closely spaced bands of biotite, hornblende, quartzo-feldspathic materials, etc. which have generally good foliation.

Granitic gneiss and semi-felsitic gneiss are also seen in some places. Granitic gneiss is less foliated than the mafic gneiss, pinkish colored, medium to coarse grained, formed by quartz, feldspar, biotite, etc. in general. Pegmatitic zones are sometimes seen. Semi-felsitic gneiss is well foliated, light grey to greenish grey colored, formed by quartz, feldspar, biotite, hornblende, etc.

The bedrocks is generally deeply weathered. The mafic gneiss tends to be the most highly weathered, being compared with the granitic gneiss and semi-felsitic gneiss. The results of the drilling investigation reveal that the bedrock is typically weathered to a depth of several meters to 18m maximum. Ridge topography and hills are generally formed by granitic gneiss or semi-felsitic gneiss, and rather flat/wide and gentle slopes are formed by mafic gneiss.

Younger sedimentary rocks (sandstone, limestone, etc.) are seen in some areas narrowly, thinly and discontinuously.

Foliation of the gneisses strikes consistently to the north-northeast and dips generally steeply to the west-northwest. Major joint structures also are generally in a similar direction and dip of the foliation. Other joint structures are the strike of west-east and almost vertical dip, showing direction similar to the Tana river flow, as observed on the outcrops distributed along both banks of the Tana river.

No major fault structures were identified in the damsite area. Some minor crushed and sheared zones were observed on the rock outcrops on both banks of the Tana river and of the seasonal rivers.

The geological map and geological profiles are shown in Figure C1.3.2 and C2.1 to C2.9 of the Annex-C, respectively.

(3) Geology of dam foundation

The upper half of the left bank slope is rather steep, 20-30 degrees, where gneisses (highly to moderately weathered) are well outcropped. Moderately to slightly weathered gneisses are seen along both banks in the river channel. River bed deposit seems to be rather thin, several meters in maximum thickness. At the bore hole G95-8, the thickness of the deposit is 2m. The right bank is formed by gently sloped hills with less outcrops of rock than that in the left bank.

The foundation rocks are mainly granitic gneiss in the left abutment, and semi-felsic/granitic gneisses, partly mafic gneiss in the right abutment.

Main joint structures are as follows.

Table: Major Joint Structure

Strike/dip	
N20-40°E/60-80°NW:	Along foliation, several 10cm to 1m intervals approximately.
N70-80°W/vertical:	Similar to the river flow direction, several 10cm to 1m intervals approximately.

Source: JICA Study Team

(a) Excavation line for dam core zone trench

The weathering condition of foundation rock on both abutments, which are observed in the drilled bore holes, is shown in Table C1.3.6.

From the results of the drilling investigation, the depth of the slightly weathered rock surface in both abutments is estimated for each alternative dam axis as follows:

Table: Rock Weathewring Conditions

"line A-D-B" (upstream)

Depth of moderately - slightly weathered rock (CM-CH class rock) surface (m)

Left abutment	4.20 - 9.00 - 3.00	(G95-1, G95-2 & G95-3)
River bed	10.00 approx.	(94-3)
Right abutment	4.05 - 14.05 -17.80 - 10.10	(BH-3, BH-2, BH-1 & BH-4)
	6.75 - 11.20 - 5.50 - 2.40	(94-2, G95-4, 94-1 & G95-5)

"line C-D-B" (midstream)

Depth of moderately - slightly weathered rock (CM-CH class rock) surface (m)

Left abutment	1.50 - 7.00	(G95-6 & G95-7)
River bed	2.00	(G95-8)
Right abutment	14.30 - 10.60 -14.05	(G95-9, G95-10 & BH-2)
	11.20 - 5.50 - 2.40	(G95-4, 94-1 & G95-5)

"line E-F-G" (downstrema) (River bed: No drill hole)

Depth of moderately - slightly weathered rock (CM-CH class rock) surface

Left abutment	1.50 - 7.00	(G95-6 & G95-7)
Right abutment	16.00 - 12.20 -15.00 - 1.80	(G95-11, G95-12, G95-13 & G95-14)

Source: JICA Study Team

Below the highly to moderately weathered rock, moderately to slightly weathered rock exist. Moderately to slightly weathered rock which corresponds to the seismic velocity zones more than 2.8km/sec will be appropriate for the foundation of a core zone of rock fill type dam, and for the foundation of a concrete gravity dam. Therefore, 3 to 9 meters excavation for the left abutment, and 5 to 15 meters or more excavation in the right abutment will be required. The excavation depth in the river channel is estimated to be 2 - 5m in general, while the core sample in the bore hole 94-3, which is an inclined hole of 60°, shows CL class rock up to 10m deep.

Seismic survey was performed for the alternative dam axes in 1995. The results are shown in Table C1.3.7 and in the geological profiles in Figure C2.1 to C2.9 in Annex-C.

The depth of the zones which have seismic velocity of more than 2.8-3.0 km/sec CM-CH-B class rocks) for each alternative dam axis is approximately as follows.

Table: Surface Burden Depth (Depth and St. length: approximately)

"line A-D-B" (upstream)

	Line	Depth of more than 2.8-3.0km/sec(m)
Left abutment	G95-C	5 - 10m
Right abutment	G95-D	10 - 15m,
		partly 20 - 25m (near G95-9, between G95-10 and GH-2)
	G95-B	5 - 10m between the river and St. 700m
		15 - 25m between St. 700m and 1,250m
		10 - 15m between St. 1,250m and the end of the line

"line C-D-B" (midstream)

	Line	Depth of more than 2.8-3.0km/sec(m)
Left abutment	G95-C	5 - 10m
Right abutment	G95-D	10 - 15m,
		partly 20 - 25m (near G95-9, between G95-10 amd GH-2)
	G95-B	5 - 10m between the river and St. 700m
		15 - 25m between St. 700m and 1,250m
		10 - 15m between St. 1,250m and the end of the line

"line E-F-G" (downstrem)

	Line	Depth of more than 2.8-3.0km/sec (m)
Left abutment	G95-E	5 - 15m
Right abutment	G95-F	10 - 20m between the river and St. 300m
		5 - 10m between St. 300m and the end of the line
	G95-F	5 - 10m

Source: JICA Study Team

Some low velocity zones are found in the seismic survey results as shown in Table C1.3.7 and in the geological profiles. These may suggest the existence of fault structures which have some fractured zones. However, in general the fractured zones of these fault structures observed in the field and in the drilling core samples are confirmed to be mostly re-consolidated, hard and in good condition, without any thick clayey zones while they have more joints and are sometimes more friable zones than the normal rock.

The rocks except decomposed soft rocks and river sand/gravel deposit will be appropriate for the shell zone foundation of the fill type dam in principle.

(b) Rock properties of foundation rock

The rock properties can be estimated based on the field investigation results, and the correlation established by Dr. K. Kikuchi, et al. (1982) as shown in Table C1.3.9 which was made by using the results obtained by field investigations, such as seismic refraction survey, in-situ rock shear test, in-situ plate loading test, etc. Dr. Kikuchi suggests that rocks are classified into three groups based on those hardness as below:

Table: Rock Classification

Rock group	Uniaxial compressive strength (kgf/cm^2)
Hard rocks	800 or more
Medium hard rocks	200 - 800
Soft rocks	200 or less

The rock classification for the Project is shown in Tables C1.3.8.It is applied to drilling logs of all bore holes performed in 1994 - 1995.

A seismic survey was carried out by EPDC in 1979 and by JICA Study Team in 1995. According to the results of the survey, the relation between the geological condition and the seismic velocity (Vp) are summarised as follows:

Table: Seismic Survey and Geological Condition

Layer	Vp (km/sec)	Geological condition
Survey results performed by EPDC		
1	0.6-1.2	alluvium, residual soil, etc.
2	1.5-3.7	highly to slightly weathered rocks
3	3.4-6.3	slightly weathered to fresh rocks

Survey results performed JICA in 1995		
1st zone	0.5-0.8	Residual soil, river deposit, decomposed rocks, etc.
2nd zone	1.5-2.0	D & CL-CM: Highly to moderately weathered rocks
3rd zone	2.8-3.2	CM-CH: Moderately to slightly weathered rocks
4th zone	5.0-6.0 or more	CH-B: Fresh rocks

According to the results of laboratory tests on rock core samples previously carried out in the Mutonga dam site (1979), compressive strength of gneisses is 650 - 1,000 kgf/cm^2. The rocks in the Mutonga damsite are also mainly the same type of gneisses in the same formations of the Kenyan Basement System as the rock in the Grand Falls damsite.

The results of laboratory tests un this study (1995) on rock core samples carried out in both the Mutonga and the Grand Falls projects are summarized as followes.

	compressive strength (kg/cm^2)
samples in Mutonga damsite	
Depth between 4.90m and 5.40m in No.M95-3	297
Depth between 21.80m and 22.50m in No.M95-3	954
Depth between 9.80m and 10.30m in No.M95-4	487
samples in Grand Falls damsite	
Depth between 10.70m and 11.00m in No.M95-8	441
Depth between 18.60m and 19.10m in No.M95-8	913
Depth between 14.20m and 14.50m in No.M95-10	683

Consequently, it can be said that the foundation rock of the damsite is medium hard rock, and the rock properties of those in moderately - slightly weathered to fresh condition (CM-CH-B) are estimated to be in the range of "Rock class C to B" of the Table C1.3.9, which are appropriate properties as the foundation of a high dam, both of fill type and concrete gravity type.

(c) Permeability of foundation rock

The permeability test results are summarised in Table C1.3.10. High pervious rock of more than 10 Lugeon or coefficient of permeability of more than $1.0x10^{-4}$ cm/sec, is seen in the zones above the following depth in both abutments for each alternative dam axis.

Table: Depth of Sufficiently Low-Pervious Rock Surface

(Unit: m)

"line A-D-B" (upstream)					
Left abutment	6.05	- 17.35	-30.20		(G95-1, G95-2 & G95-3)
River bed	10.00	approx.			(94-3)
Right abutment	9.00	- 6.00	-23.50	- 18.55	(BH-3, BH-2, BH-1 & BH-4)
	13.50	- 19.60	-14.55	- 12.00	(94-2, G95-4, 94-1 & G95-5)
"line C-D-B" (midstream)					
Left abutment	13.00	- 9.40			(G95-6 & G95-7)
River bed	35.10				(G95-8)
Right abutment	26.00	- 19.10	- 6.00		(G95-9, G95-10 & BH-2)
	19.60	- 14.55	-12.00		(G95-4, 94-1 & G95-5)
"line E-F-G" (downstrema)					(River bed: No drill hole)
Left abutment	13.00	- 9.40			(G95-6 & G95-7)
Right abutment	9.00	- 19.75	-19.20	- 32.30	(G95-11, G95-12, G95-13 & G95-14)

The zones below the depth, show very low permeability, almost impermeable. Foundation treatment will be required for the depth in principle.

(d) Groundwater condition

The groundwater condition is estimated by the water level record measured in the investigation bore holes. All the records are shown in the Annex-C. The water levels measured in the bore holes for each alternative axis are summarised as follows.

Table: Ground Water Level

(94-3: Inclined hole; 3.00m>>2.6m)

Hole No.	EL. of hole mouth (m)	Depth & (EL.) of water level (m)		Location
"line A-D-B" (upstream axis)				
G95-1	520.37	17.05	(503.32)	Left bank
G95-2	493.42	18.35	(475.07)	Left bank
G95-3	478.76	19.05	(459.71)	Left bank
94-3	444.20	3.00	(441.60)	River bed
94-2	474.36	21.10	(453.26)	Right bank
G95-4	505.59	23.60	(481.99)	Right bank
94-1	495.66	29.05	(466.61)	Right bank
G95-5	530.37	24.30	(506.07)	Right bank
"line C-D-B" (midstream axis)				
94-4	536.62	45.65	(490.97)	Left bank
G95-6	522.82	13.00	(509.82)	Left bank
G95-7	492.71	13.55	(479.16)	Left bank
G95-8	442.97	1.30	(441.67)	River bed
G95-9	464.46	20.80	(443.66)	Right bank
G95-10	473.62	22.70	(450.92)	Right bank
G95-4	505.59	23.60	(481.99)	Right bank
94-1	495.66	29.05	(466.61)	Right bank
G95-5	530.37	24.30	(506.07)	Right bank
"line E-F-G" (downstream axis)				
94-4	536.62	45.65	(490.97)	Left bank
G95-6	522.82	13.00	(509.82)	Left bank
G95-7	492.71	13.55	(479.16)	Left bank
G95-8	442.97	1.30	(441.67)	River bed
G95-11	465.06	16.10	(448.96)	Right bank
G95-12	491.83	28.60	(463.23)	Right bank
G95-13	484.45	23.90	(450.55)	Right bank
G95-14	521.78	37.30	(484.83)	Right bank

Source: JICA Study Team

In the Table above mentioned, the record of bore holes 94-1, 94-2, 94-3 and 94-4 which were drilled in 1994, are the depths measured at the final day of drilling work for every hole, and the records in the other holes which were drilled in 1995, are the deepest depths measured after the completion of drilling work (refer to the Supporting Report).

Hole No. 94-3 is located in the river bed. Therefore, the water level in this hole shows the Tana river water level at dam site approximately. The water levels in the other holes because higher than that in the No. 94-3 (Tana river water level).This means that the groundwater level in this area rises toward the mountain side from the river side in both banks. The results obtained through the present investigation are almost similar to the results of the previous investigation performed by UN/World Bank/Acres (1987).

(4) Foundation treatment of dam

The following grouting works will be required for the dam foundation

For rock fill dam

a. Curtain grouting;	Along the dam axis. Two lines, 2 - 3m hole spacing.
b. Blanket grouting;	All the foundation area of impervious core zone. Depth of 5m, with 3m grid.
c. Consolidation grouting;	For the spillway weir foundation. Depth of 5m, with 3m grid.

For combine type dam

a. Curtain grouting;	Along the dam axis. Two lines, 2 - 3m hole spacing.
b. Consolidation grouting;	All the foundation area of concrete dam. Depth of 5m, with 3m grid.
c. Blanket grouting;	all the foundation area of imprevious core zone in rock fill dam section. Depth of 5m, with 3m grid.

The curtain grouting hole depth will be 10 to 40m in general, considering the permeability condition of the foundation rocks.

(5) Geology on other structures

(a) Diversion tunnel

The diversion tunnel will be on the left bank near the bore holes No. G95-3 and G95-7, or on the right bank near the bore holes No. 94-2 and G95-10.

Bore holes 95-3 and G95-7 in the left bank show the following rock condition:

Table: Rock Condition along Route of Diversion Tunnel in Left Bank

Hole No.	Depth (m)	Rock condition
G95-3	0.00 - 3.00	Rs & highly to slightly weathered (D-CM)
	3.00 - 35.50	slightly weathered to fresh (CH-B)
G95-7	0.00 - 7.00	Rs & highly to moderately weathered (D-CL, partly CM)
	7.00 - 30.05	slightly weathered to fresh (CH-B, partly CM)

Abbrevation: Rs; Residual Soil

Source: JICA Study Team

Bore holes 94-2 and G95-10 in the right bank show the following rock condition:

Table: Rock Condition along Route of Diversion Tunnel in Right Bank

Hole No.	Depth (m)	Rock condition
G94-2	0.00 - 6.75	residual soil & highly weathered rock
	6.75 - 10.30	moderately to highly weathered rock
	10.30 - 15.40	moderately weathered rock
	15.40 - 75.00	slightly weathered to fresh rock
G95-7	0.00 - 10.60	Rs & highly to moderately weathered (D-CL)
	10.60 - 30.20	slightly weathered to fresh (CH-B)

Abbrevation: Rs; Residual Soil

Source: JICA Study Team

According to the rock conditions mentioned above, the foundation from the ground surface to the depth of about 3 to 7m in the left bank and 10 to 15m in the right bank is formed by residual soil and moderately to highly weathered rocks.

On the left bank, the tunnel depth (ceiling) will be about 20 to 30m so that 13 to 23m of moderately to slightly weathered rock covers the tunnel at the position of the bore hole No. G95-7. On the right bank, the tunnel depth (ceiling) will be about 20 to 25m which means that 10 to 15m of moderately to slightly weathered rocks cover the tunnel at the position of the bore hole No. G94-2.

A seismic survey was performed for the possible tunnel routes in the both banks in 1995. The results are shown in Table C1.3.7 and in the geological profiles presented in the Annex-C. The results show that the zone which have a seismic velocity of more than 2.8 km/sec (CM-CH-B class rocks) exist very deep portion of more than 15 - 30m from the surface on the right bank, while it is 10 - 20m deep in the left bank.

Consequently, the diversion tunnel location had better be shifted toward the mountain (south) to get thicker cover rock in the right bank, or had better be in the left bank.

(b) Spillway

The spillway for the rock fill type dam is proposed to be in the left bank, the north side of the dam. The depth of moderately to slightly weathered rock surface in the bore holes located in the right abutment is estimated to be as follows:

Table: Spillway Geology

Hole No.	Depth of moderately to slightly weathered rock surface (m)
G95-1	4.30
G95-2	9.00
G95-6	1.50
BH-5	3.62
BH-6	8.05
94-4	7.70

Source: JICA Study Team

Below the above mentioned depth, the rock is moderately to slightly weathered or fresh, which will be appropriate as the spillway foundation.

(c) Power house and intake structures

Both banks of the Tana river will be geologically acceptable for the construction of the power house for both the fill type dam and concrete gravity dam. According to the previous design, the site is located on the left bank and some deep open excavation will be required. As the power house location will be close to the river, it is anticipated that the surface zones of highly weathered rock will be thin and the excavation will be in good quality rock in general.

For the fill type dam, an waterway tunnel with a length of 300-500m will be required from the dam reservoir to the power house. If the tunnel is designed at the elevation above diversion tunnel, more tunnel support work will be required than those of the diversion tunnel, because the tunnel will penetrate through shallow rock zones which is more highly weathered than that in the deeper zones. Deeper tunnel may be recommendable.

A waterway tunnel will not be required for the concrete gravity dam. The intake structure will be constructed in the concrete dam body.

C1.4 Seismicity and Seismic Risk

C1.4.1 Earthquakes and seismic zones in Kenya

According to I.S.Loupekine, a catalog of felt earthquakes in Kenya for the period of 1892-1969 (78 years) is given in the following table.

Total number of earthquakes for the period of 1892-1969

Maximum magnitude (MM)	Number of earthquakes
IX	1
VIII	o
VII	3
VI	28
V	128
IV	382
III-II	25
Total	567

(MM): Modified Mercalli Scale (Wood and Neuman, 1931)

Distribution of widely felt earthquakes and major faults (refer to Figure C1.4.4) in Kenya is shown in Figure C1.4.6, which illustrates the areas affected by tremors producing intensity effects of at least V on the Modified Mercalli Scale.

A seismic zone map produced by I.S.Loupekine is shown in Figure C1.4.5. According to Loupekin (1971), the influence of earthquakes on buildings and other structures in various zones are as follows.

A Catalog of Felt Earthquakes in Kenya (1892-1969)

- IX Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great, in substantial buildings, with partial collapse. Buildings shifted off foundations. Underground pipes broken. (These effects are believed to obtain only locally in Zone VIII-IX, shown in the Seismic Zone Map.)
- VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls.
- VII Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken.
- VI A few instances of fallen plaster or damaged chimneys. Damage slight.
- V A few instances of cracked plaster.

The project site is located in the Zone V which is the lowest seismic zone in Kenya.

C1.4.2 Seismic coefficient for dam design

The design seismicity for the dams of the Mutonga/Grand falls Project is reviewed through estimation of the probable maximum accelerations in the return periods of 100 years and 200 years , and estimation of maximum credible earthquake, based on the earthquake record of the years from 1906 to 1994 for the area within a distance of 500 km from the Grand Falls damsite. The earthquake record which is shown in Table C1.4.1 has been obtained from the British Geological Survey, Edinburgh, U.K. The location of Grand Falls damsite is selected as the project site for this study. The location of each earthquake is shown in Figure C1.4.3.

The formulas utilized in this study are as follows.

$Imm = 8.0 + 1.5\ M - 2.5\ Ln(d^2 + h^2 + 400)^{0.5}$	Cornell	(1)
$Log\ a = Imm / 3 - 0.5$	Richter	(2)
$a = 2000\ e^{0.8M} / (d^2 + h^2 + 400)$	Cornell	(3)
$a = 5000\ e^{0.8M} / (r + 40)^2$	Estava	(4)
$Ij = 2\ M - 4.6052\ Log\ d - 0.00183\ d - 0.307$ (for "d" not less than 100 km)	Kawasumi	(5)
$Ij = 2\ (M - Log\ r) - 0.01668\ r - 3.9916$ (for "d" less than 100 km)		
$a = 0.45 \times 10^{(Ij/2)}$ (for "Ij" not more than 5.5)	Kawasumi	(6)
$a = 20 \times 10^{(Ij/5)}$ (for "Ij" more than 5.5)		

Where,

- Imm : Intensity in Modified Mercalli Scale (MM)
- Ij : Intensity in Japan Meteorological Agency Scale
- M : Magnitude of earthquake in Richter Scale
- d : Distance from epicenter to the project site in km
- h : Depth of focus in km
- r : Distance from focus to the project site in km
- a : Peak ground acceleration in gal or cm/sec^2
- e : The exponential constant

Accelerations are estimated by the methods of Cornell, Estava and Kawasumi for comparison. Intensity and ground accelerations, at the project site, of the earthquakes which are estimated to have been felt at the site are shown in Table C1.4.1.

(1) Cornell's method

The estimation of maximum earthquake intensity and peak ground acceleration is made according to Cornell's method. Intensities (Imm) of each earthquake are calculated by the formula (1), and shown in Table 1. While the total number of earthquakes is 258 cases, according to the formula (1), the intensities of 230 cases are zero or minus, and only 28 cases are more than zero which are shown in Table 2 as the selected earthquakes for the estimation of probable maximum intensity.

The probable maximum earthquake acceleration (a) is calculated from probable maximum intensity, by the use of the formula (2) presented above. The probable maximum intensity is estimated from recorded numbers of earthquakes exceeding given intensities, according to Gutemberg's linear relation between the intensity and the logarithm of the frequency of earthquakes exceeding it.

The total annual frequencies for earthquakes exceeding intensities of each grade are plotted on logarithm - normal graphs as shown in Figures C1.4.1 and C1.4.2, to obtain the linear relations between the intensity exceeded and the logarithm of the frequency. The probable maximum intensities and accelerations for the return periods of 100 years and 200years are summarized in Table C1.4.2, and as follows.

0.01g for the return period of 100years

0.03g for the return period of 200 years

These figures indicate that a design seismic coefficient of 0.01g for the return period of 100years and/or 0.03g for the return period of 200 years can be applied to this project.

(2) Maximum credible earthquake

Figure C1.4.6 shows the distribution of measure faults and earthquakes. According to Figure C1.4.6, most of measure earthquakes distribute along these faults which run with north - south direction (Lake Rudolf - Lake Naivasha - Lake Magadi) in the west of the project site.

There is one fault runs north - south direction, located for about 50 km far to the southeast from the project site. While no notable earthquakes can be seen along this fault in the Figure, it can be said that there is a few possibility to occur earthquakes in this fault also. The following maximum credible earthquake (MCE-1) is estimated on this fault.

Depth(km)	Magnitude	Distance(km)
25.00	6.0	50

The biggest and nearest earthquake to the project site is selected from the record (Subukia, 1928 in Figure C1.4.6 / No.4 in Table C1.4.1). This earthquake locates in the northwest of the project site. As the maximum credible earthquake, the location of this earthquake is shifted toward south along the faults to obtain minimum distance (150 km approximately) between this earthquake and the project site. Then, the maximum credible earthquake (MCE-2) on this earthquake and faults is estimated to be as below.

Depth(km)	Magnitude	Distance(km)
36.50	7.0	150

The peak acceleration at the project site on this earthquake is estimated by the Cornell's formulas (1) and (2), Kawasumi's formurlas (5) and (6), and Estava's formula (4), to be as follows.

	MCE-1		MCE-2	
	Intensity	Peak acceleration	Intensity	Peak acceleration
Cornell	6.8	68.94gal (0.070g)	6.0	23.62gal (0.024g)
kawasumi	3.6	27.78gal (0.028g)	3.4	22.48gal (0.023g)
Estava		66.06gal (0.067g)		37.46gal (0.038g)

These figures indicate that a design seismic coefficient of 0.023g to 0.070g can be applied to this project.

(3) Conclusion

The results of Cornell's method indicate that a design seismic coefficient of 0.01g for the return period of 100years and/or 0.03g for the return period of 200 years can be applied to this project. The maximum credible earthquake indicates that 0.023g to 0.070g can be applied to this project.

The Kiambere dam is located in the upstream of the Mutonga damsite, in the border area of seismic zones VI and V. Mutonga and Grand Falls dams are located in the seismic zone of V (refer to clause C1.4.1). The foundation rocks of the Kiambere dam are formed by mainly the same type of gneisses in the same formations of the Kenyan Basement System as the rocks in the Mutonga and Grand Falls damsites. A value of k = 0.12g is adopted for the Kiambere project as a seismic coefficient to occur once in 100 years. Lower seismic coefficient for this project than that of Kiambere dam can be applied considering these locations in the seismic zone map.

Taking these conditions into consideration, the design seismic coefficient of 0.10g for the design in the Mutonga/Grand Falls project is deemed reasonably conservative.

C1.4.3 Reservoir induced seismicity (RIS)

Many examples of earthquakes occured during initial impounding of reservoirs are seen in those reservoirs having depth of more than 100 meters, such as Konya dam in India, Hoover dam in USA, etc. These examples often suggested an interrelation between reservoir filling and earthquake occurrence. The cause of these earthquakes is generally explained by release of preexisting stress, which will be released upon fault movement being caused mainly by increased load of reservoir water and pore pressure in rocks. These earthquakes are small to medium in general, mostly of magnitude less than 6. In the case of the Hoover dem, the maximum earthquake was magnitude 5 in the surrounding area of the reservoir (Dictionary of Earthquakes, T.Utsu, 1987, Tokyo).

The maximum depth of the Mutonga / Grand Falls reservoirs will be 70 - 80 meters in maximum, therefore a possibility that the impounding of the reservoir will induce of earthquakes will be very low compare to the examples mentioned above. Even though, such earthquakes will occur, it can be said that the ground acceleration to be anticipated at the damsite will be much less than the design seismic coefficient (0.10g).

In the Magwagwa project in Kenya, the design seismic coefficient is estimated to be k = 0.10g. According to the Report on the Magwagwa project, the expected maximum acceleration of the reservoir induced seismicity (RIS) for the project is estimated to be 0.05g which is judged to be within the range of safety for the dam to be designed as k = 0.10g. The same explanation may be adopted for the Mutonga / Grand Falls projects.

Consequently, no specific consideration will be required on the reservoir induced earthquakes for this project.

Table C1.3.1 Geological investigation performed in 1995 (Mutonga)

Boring Investigation (1995)

Hole No.	Location Northing	Easting	Elevation (m)	Depth (m)	Inclination (deg.)	Lu. test (nos)
M95-1	9,953,043.65	382,391.11	554.595	45.00	90	8
M95-2	9,952,978.41	382,372.66	537.585	30.15	90	5
M95-3	9,952,838.43	382,330.74	512.981	50.30	90	9
M95-4	9,952,696.04	382,288.82	535.836	30.00	90	5
M95-5	9,952,528.75	382,238.43	549.146	50.20	90	9
M95-6	9,953,442.83	382,557.00	553.490	30.00	90	4
M95-7	9,953,360.55	382,563.81	553.351	10.10	90	0
MQ95-1	9,951,746.57	382,100.05	609.510	30.00	90	0
Total Quantity				275.75		40

Seismic Survey (1995)

Line	Length (m)
M95-A	290
M95-B	460
M95-C	690
M95-D	575
M95-E	625
M95-F	460
Total Length	3,100

Laboratory test for dam foundation rocks

Specific gravity and absorption test (ASTM C127, C128): 3 samples.
Uni-axial compression test (ASTM D2938-86): 3 samples.

Sample: Depth between 4.90m and 5.40m in bore hole No.M95-3
Depth between 21.80m and 22.50m in bore hole No.M95-3
Depth between 9.80m and 10.30m in bore hole No.M95-4

Petrographic Microscope Study

Sample: 6.5 m depth in bore hole No. M95-1
22.5 m depth in bore hole No. M95-2

Table C1.3.2 Weathering Condition Observed in Boreholes (Mutonga)

(A) Results of previous drilling investigation (1979/1980)

Hole No.	Depth (m)	Weathering condition
MDD1	0.00 - 3.50	Rs & highly to moderately weathered
	3.50 - 35.22	slightly - faintly weathered to fresh
MDD2	0.00 - 14.20	no core recovery
	14.20 - 15.20	highly weathered
	15.20 - 16.40	highly to moderately weathered
	16.40 - 35.22	slightly - faintly weathered to fresh
MDD3	0.00 - 5.50	Rs & completely to highly weathered
	5.50 - 6.10	moderately weathered
	6.10 - 25.28	slightly-faintly weathered to fresh

(Rs: Residual soil)

(B) Results of drilling investigation in this stage (1995)

Hole No.	Depth (m)	Weathering condition (Rock classification)
M95-1	0.00 - 3.20	Rs & highly to moderately weathered (D-CM)
	3.20 - 45.00	slightly weathered (CH)
M95-2	0.00 - 9.35	Rs & highly to moderately weathered (D-CM)
	9.35 - 30.15	slightly weathered to fresh (CH-B)
M95-3	0.00 - 3.00	Rd
	3.00 - 50.30	slightly weathered (CH, partly CL-CM)
M95-4	0.00 - 5.20	Rs & highly to moderately weathered (D-CM)
	5.20 - 6.20	moderately weathered (CM)
	6.20 - 30.00	slightly weathered to fresh (CH-B)
M95-5	0.00 - 4.70	Rs & highly to moderately weathered (D-CM)
	4.70 - 9.85	moderately to slightly weathered (CL-CM)
	9.85 - 50.20	slightly weathered to fresh (CH-B)

(Rs: Residual soil, Rd: River bed deposit)

Table C1.3.3 Seismic Survey Results (Mutonga)

(A) Relation between Seismic Velocity (P-wave) and Rock Classification

Borehole No. M95-1 (45.00m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.6	0.00 - 2.00	Rs & D
1.5 - 1.8	2.00 - 12.00	(CM) & CH
3.0 - 3.2	12.00 - 23.00	CH
6.0	below 23.00	CH

Borehole No. M95-2 (30.15m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.8	0.00 - 2.00	Rs
1.6 - 1.8	2.00 - 10.00	CL & CM
3.0 - 3.2	10.00 - 21.00	CH & (CL, CM)
5.8 - 6.0	below 21.00	B

Borehole No. M95-3 (50.30m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.7	0.00 - 1.50	Rd
1.6 - 1.9	1.50 - 4.00	Rd & CM, CH
3.0 - 3.2	4.00 - 10.00	CM, CH & (CL)
5.6	below 10.00	CH & (CL, CM)

Borehole No. M95-4 (30.00m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.7	0.00 - 1.50	Rs
1.6 - 1.9	1.50 - 12.00	D, CL, CM & CH
3.0 - 3.2	12.00 - 32.00	CH & B
5.6	below 32.00	

Borehole No. M95-5 (50.20m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.8	0.00 - 2.00	Rs
1.5 - 1.8	2.00 - 9.00	D, CL & CM
2.8 - 3.0	9.00 - 26.00	CH & (CL, CM)
5.6 - 5.8	below 26.00	CH

Borehole No. M95-6 (30.00m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.7	0.00 - 4.00	Rs & D
1.8 - 2.0	4.00 - 15.00	(D), CL & CM
3.0 - 3.2	15.00 - 36.00	CM & CH
6.0	below 36.00	CH & (CM)

Borehole No. M95-7 (10.10m: River bed)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.8	0.00 - 2.00	Rd
1.6 - 1.8	2.00 - 17.00	D, CL, CM & CH
3.0 - 3.2	17.00 - 39.00	
5.3	below 39.00	

Rs: Residual soil
Rd: River bed deposit
Depth: approximately

(B) Low velocity zone

Line	Distance (m)	Vp (km/sec)	
M95-A	65 - 80	3.0	
	120 - 130	2.0	near M95-1
	200 - 220	3.2	near M95-2
M95-B	125 - 130	3.0-3.2	
	390 - 400	2.7	
M95-C	65 - 70	3.0-3.2	
	120 - 130	3.5	
	490 - 500	3.1	
	590 - 600	2.2	
M95-D	85 - 90	2.9-3.1	
	180 - 190	2.7	
	250 - 255	2.8-3.2	
	490 - 515	3.8	
M95-E	130 - 140	3.4	
	255 - 265	2.0	
M95-F	215 - 225	2.4	
	330 - 335	3.0	

Table C1.3.4 Permeability Condition Observed in Boreholes (Mutonga)

(A) Results of previous drilling investigation (1979/1980)

Hole No.	Depth (m)	Lugeon values
MDD1	0.00 - 10.00	more than 100
	10.00 - 19.90	1.5 - 2.5
	19.90 - 35.22	impermeable
MDD2	0.00 - 14.20	no data
	14.20 - 24.00	24 - 34
	24.00 - 35.22	0.45 - 2.4
MDD3	0.00 - 10.70	no data
	10.70 - 20.00	15 - 20
	20.00 - 25.28	0.3

(B) Results of drilling investigation in this stage (1995)

Hole No.	Depth (m)	Lugeon values
M95-1	0.00 - 3.80	no data
	3.80 - 13.20	218.9-363.4
	13.20 - 45.00	0-5.1
M95-2	0.00 - 4.00	no data
	4.00 - 9.00	64.6
	9.00 - 10.30	no data
	10.30 - 30.15	0-4.8
M95-3	0.00 - 5.50	no data
	5.50 - 10.10	2.6
	10.10 - 15.00	7.2
	15.00 - 50.30	0-2.0
M95-4	0.00 - 7.70	no data
	7.70 - 12.70	9.3
	12.70 - 30.00	0-0.3
M95-5	0.00 - 3.00	no data
	3.00 - 7.20	34.0
	7.20 - 10.10	no data
	10.10 - 20.05	18.4-46.0
	20.05 - 50.20	0-0.4

Table C1.3.5 Geological investigation performed in 1994 - 1995 (Grand Falls)

(A) Geological investigation for pre-feasibility study performed in 1994

Boring Investigation

Hole No.	Location Northing	Easting	Elevation (m)	Depth (m)	Inclination (deg.)	Azimuth (deg.)	Lu. test (nos)
94-1	9,968,810.45	392,179.63	495.66	100.20	90		19
94-2	9,969,586.43	392,526.14	474.36	75.00	90		13
94-3	9,969,832.02	392,653.23	444.20	100.25	60	205	19
94-4	9,970,218.55	393,155.71	536.62	125.35	90		24
Total Quantity				400.80			75

(Azimuth: From North)

(B) Geological investigation for feasibility study performed in 1995

Boring investigation

Hole No.	Location Northing	Easting	Elevation (m)	Depth (m)	Lu. test (nos)
G95-1	9,970,390.11	392,886.02	520.37	50.50	9
G95-2	9,970,147.87	392,777.42	493.42	30.00	5
G95-3	9,969,954.38	392,690.60	478.76	35.50	6
G95-4	9,969,299.91	392,397.06	505.59	50.25	8
G95-5	9,968,518.63	392,051.75	530.37	50.00	8
G95-6	9,969,956.60	393,066.82	522.82	80.15	16
G95-7	9,969,880.85	392,989.38	492.71	30.05	4
G95-8	9,969,746.24	392,853.92	442.97	50.20	9
G95-9	9,969,657.03	392,760.12	464.46	30.15	5
G95-10	9,969,522.46	392,627.47	473.62	30.20	4
G95-11	9,969,570.23	393,038.41	465.06	30.25	5
G95-12	9,969,160.65	393,010.72	491.83	30.10	4
G95-13	9,968,950.26	392,922.39	484.45	30.10	4
G95-14	9,968,403.07	392,695.85	521.78	50.20	9
GQ95-1	9,967,854.36	392,079.64	572.15	30.25	0
Total Quantity				607.90	96

(Hole inclination is vertical for all holes.)

Seismic Survey

Line	Length (m)
G95-A	690
G95-B	1,495
G95-C	345
G95-D	750
G95-E	345
G95-F	630
G95-G	1,035
G95-H	1,035
G95-I	575
Total Length	6,900

Laboratory test for dam foundation rocks (1995)

Specific gravity and absorption test (ASTM C127, C128): 3 samples.
Uni-axial compression test (ASTM D2938-86): 3 samples.

Sample: Depth between 10.70m and 11.00m in bore hole No.G95-8
Depth between 18.60m and 19.10m in bore hole No.G95-8
Depth between 14.20m and 14.50m in bore hole No.G95-10

Petrographic Microscope Study (1995)

Sample: 21.3 m depth in bore hole No.95-2
16.6 m depth in bore hole No.95-10
19.3 m depth in bore hole No. 95-10
13.6 m depth in bore hole No. 95-14

Table C1.3.6 (1) Weathering Condition Observed in Boreholes (Grand Falls)

(A) Boreholes drilled by UN/World Bank (1987)

Hole No.	Depth (m)	Weathering condition	Location
BH-4	0.00 - 8.40	Rs & slightly to moderately weathered	Right bank
	8.40 - 10.10	moderately weathered	
	10.10 - 13.56	slightly-moderately weathered	
	13.56 - 23.25	slightly weathered to fresh	
BH-1	0.00 - 2.00	Rs & highly weathered	Right bank
	2.00 - 16.95	slightly-highly weathered	
	16.95 - 17.80	moderately weathered	
	17.80 - 30.25	slightly-partly moderately weathered	
BH-2	0.00 - 5.38	Rs & slightly-completely weathered	Right bank
	5.38 - 6.85	moderately-completely weathered	
	6.85 - 14.05	highly-completely weathered	
	14.05 - 25.45	moderately weathered to fresh	
BH-3	0.00 - 4.05	Rs & moderately to highly weathered	Right bank
	4.05 - 40.45	slightly weathered to fresh	
BH-5	0.00 - 3.62	Rs & highly weathered	Left bank
	3.62 - 19.00	slightly weathered to fresh	
BH-6	0.00 - 1.00	Rs	Left bank
	1.00 - 8.05	moderately-highly weathered	
	8.05 - 10.50	slightly weathered	
BH-7	0.00 - 14.30	highly weathered	Left bank
	14.30 - 15.50	slightly weathered	

(Rs: Residual soil)

(B) Boreholes drilled in this stage (1994)

Hole No.	Depth (m)	Weathering condition (Rock classification)
94-1	0.00 - 5.50	Rs & slightly to highly weathered (D-CM)
	5.50 - 8.55	moderately weathered (CM)
	8.55 - 100.20	slightly weathered to fresh (CH-B)
94-2	0.00 - 6.75	Rs & moderately weathered (CL)
	6.75 - 10.35	slightly weathered (CM, partly CH)
	10.35 - 15.40	slightly weathered (CM-CH)
	15.40 - 75.00	slightly weathered to fresh (CH-B)
94-3	0.00 - 10.30	Rd & moderately to slightly weathered (CL, partly CH)
	10.30 - 100.45	slightly weathered to fresh (CH-B)
94-4	0.00 - 7.70	Rs & highly-moderately weathered (D-CL, partly CM)
	7.70 - 10.45	moderately-slightly weathered (CM, partly CL)
	10.45 - 125.35	slightly weathered to fresh (CH-B)

(Rs: Residual soil, Rd: River bed deposit)

Table C1.3.6 (2) Weathering Condition Observed in Boreholes (Grand Falls)

(C) Boreholes drilled in this stage (1995)

Hole No.	Depth (m)	Weathering condition (Rock classification)
G95-1	0.00 - 4.30	Rs & highly to moderately weathered (D, partly CM)
	4.30 - 50.50	fresh (CH-B)
G95-2	0.00 - 9.00	Rs & moderately weathered (D-CL)
	9.00 - 30.00	slightly weathered to fresh (CH-B)
G95-3	0.00 - 3.00	Rs & highly to slightly weathered (D-CM)
	3.00 - 35.50	slightly weathered to fresh (CH-B)
G95-4	0.00 - 11.20	Rs & highly to slightly weathered (D-CL)
	11.20 - 50.25	slightly weathered to fresh (CH-B)
G95-5	0.00 - 2.40	Rs & moderately weathered (CL)
	2.40 - 50.00	slightly weathered to fresh (CH-B)
G95-6	0.00 - 1.50	Rs
	1.50 - 80.15	slightly weathered to fresh (CH-B)
G95-7	0.00 - 7.00	Rs & highly to moderately weathered (D-CL, partly CM)
	7.00 - 30.05	slightly weathered to fresh (CH-B, partly CM)
G95-8	0.00 - 2.00	Rd
	2.00 - 50.20	slightly weathered to fresh (CH-B, partly CL-CM)
G95-9	0.00 - 14.30	Rs & highly to moderately weathered (D-CL, partly CM)
	14.30 - 30.15	moderately to slightly weathered (CH, partly CL-CM)
G95-10	0.00 - 10.60	Rs & highly to moderately weathered (D-CL)
	10.60 - 30.20	slightly weathered to fresh (CH-B)
G95-11	0.00 - 8.40	Rs & highly to moderately weathered (D-CL)
	8.40 - 16.00	moderately, partly highly weathered (CM, D-CL)
	16.00 - 30.25	slightly, partly moderately weathered (CH, partly CL-CM)
G95-12	0.00 - 12.20	Rs & highly to slightly weathered (D-CL, partly CH)
	12.20 - 30.10	slightly, partly moderately weathered (CH, partly CL-CM)
G95-13	0.00 - 15.00	Rs & highly to moderately weathered (D-CL)
	15.00 - 30.10	slightly, partly moderately weathered (CH, partly D-CM)
G95-14	0.00 - 1.80	Rs & highly weathered (D)
	1.80 - 50.20	slightly weathered to fresh (CH-B, partly D-CM)

(Rs: Residual soil. Rd: River bed deposit.)

Table C1.3.7 (1) Seismic Survey Results (Grand Falls)

(A) Relation between Seismic Velocity (P-wave) and Rock Classification

Borehole No. G95-1 (50.50m: Left bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.7	0.00 - 3.50	Rs, D & (CM)
1.5 - 1.7	3.50 - 8.00	(D) & B
3.0 - 3.2	8.00 - 16.00	B
6.0	below 16.00	B, (CH)

Borehole No. G95-2 (30.10m: Left bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.8	0.00 - 1.50	Rs & D
1.8 - 2.0	1.50 - 10.00	D, CL & (CH)
2.8 - 3.0	10.00 - 40.00	CH & B
6.0	below 40.00	

Borehole No. G95-3 (35.50m: Left bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.6	0.00 - 1.00	Rs
1.8 - 2.0	1.00 - 7.00	(D, CL, CM) & CH
3.0 - 3.2	7.00 - 28.00	B
6.0	below 28.00	B, (CH)

Borehole No. G95-4 (50.25m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.8	0.00 - 1.50	Rs & D
1.8 - 2.0	1.50 - 10.00	D, CL & (CH)
2.8 - 3.0	10.00 - 35.00	CH & B
6.0	below 35.00	B

Borehole No. G95-5 (50.00m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.7	0.00 - 2.00	Rs & D
1.5 - 1.8	2.00 - 5.00	(CL) & CH
3.0 - 3.1	5.00 - 28.00	CH & B
6.0	below 28.00	B

Borehole No. G95-6 (80.15m: Left bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.6	0.00 - 1.50	Rs
1.5 - 1.7	1.50 - 7.50	CH & (CL)
3.0 - 3.2	7.50 - 25.00	CH, B & (CL)
6.0	below 25.00	B

Borehole No. G95-7 (30.05m: Left bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.6	0.00 - 1.50	Rs
1.5 - 1.6	1.50 - 8.00	D & (CL, CM)
3.0 - 3.1	8.00 - 24.00	CH & B
6.0	below 24.00	B

Borehole No. G95-8 (50.20m: River bed)

Vp (km/sec)	Depth (m)	Rock class
0.6 - 0.8	0.00 - 2.00	Rd
1.5 - 1.7	2.00 - 8.00	CH & (CM)
3.0 - 3.2	8.00 - 21.00	CH & (CL, CM)
5.6 - 6.0	below 21.00	CH & (CL, CM, B)

Borehole No. G95-9 (30.15m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.6 - 0.8	0.00 - 5.00	Rs, D, CL & CM
1.5 - 1.7	5.00 - 21.00	D, CL & (CM, CH)
3.0 - 3.2	21.00 - 37.00	CH
5.6 - 6.0	below 37.00	

Borehole No. G95-10 (30.20m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.6 - 0.8	0.00 - 2.50	Rs & D
1.6 - 1.8	2.50 - 15.00	D, CL & CH
3.0 - 3.2	15.00 - 35.00	CH & B
5.6 - 6.0	below 35.00	

Borehole No. G95-11 (30.25m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.7	0.00 - 2.00	Rs
1.5 - 1.7	2.00 - 17.00	D, CL, CM & (CH)
3.0 - 3.2	17.00 - 35.00	CM, CH & (CL)
6.0	below 35.00	

Borehole No. G95-12 (30.20m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.6	0.00 - 1.50	Rs
1.6 - 2.0	1.50 - 10.00	D, CL & (CH)
3.0 - 3.2	10.00 - 48.00	CH, B & (CL, CM)
6.0	below 48.00	

Borehole No. G95-13 (30.10m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.6	0.00 - 1.50	Rs
1.5 - 1.9	1.50 - 10.00	D & CL
2.8 - 3.0	10.00 - 35.00	D, CL, CM & CH
6.0	below 35.00	

Borehole No. G95-14 (50.20m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.6 - 0.8	0.00 - 1.00	Rs
1.7	1.00 - 9.00	D, CL, CH & (CM)
3.0	9.00 - 30.00	CM, CH & (D, CL)
6.0	below 30.00	B

Rs: Residual soil
Rd: River bed deposit
Depth: approximately

Table C1.3.7 (2) Seismic Survey Results (Grand Falls)

(B) Relation between Seismic Velocity (P-wave) and Rock Classification

Borehole No. 94-1 (100.20m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.8	0.00 - 1.50	Rs & D
1.6 - 1.8	1.50 - 22.00	(D, CL), CM & CH
2.8 - 3.0	22.00 - 56.00	D, CL, CM & CH
more than 6.0	below 56.00	CH, B & (CL, CM)

Borehole No. 94-2 (75.00m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.8	0.00 - 1.00	Rs
1.8 - 2.0	1.00 - 8.00	CL & CM
3.0 - 3.2	8.00 - 35.00	CM & CH
6.0	below 35.00	CH, B & (CM)

Borehole No. 94-3 (100.25m: River bed)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.6	0.00 - 1.50	Rd & D
1.8 - 2.0	1.50 - 10.00	CL & CH
3.0 - 3.2	10.00 - 28.00	CH, B & (CL, CM)
6.0	below 28.00	CH & B

(Depth: Along borehole)

Borehole No. BH-1 (30.25m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.8	0.00 - 3.00	Rs & HW
1.6 - 1.8	3.00 - 18.00	HW - MW
2.8 - 3.0	18.00 - 45.00	SW
more than 6.0	below 45.00	

Borehole No. BH-2 (25.45m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.7	0.00 - 3.00	Rs & HW
1.8 - 2.0	3.00 - 13.00	HW - MW
3.0 - 3.2	13.00 - 33.00	MW - SW - FR
6.0	below 33.00	

Borehole No. BH-3 (40.45m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.8	0.00 - 1.00	Rs & HW
1.8 - 2.0	1.00 - 4.50	HW
3.0 - 3.2	4.50 - 16.50	SW - FR
6.0	below 16.50	SW - FR

Borehole No. BH-4 (23.25m: Right bank)

Vp (km/sec)	Depth (m)	Rock class
0.5 - 0.7	0.00 - 1.00	Rs
1.7 - 1.9	1.00 - 12.00	HW - MW
2.8 - 3.0	12.00 - 34.00	MW - SW - FR
6.0	below 34.00	

Rs: Residual soil
Rd: River bed deposit
Depth: approximately

In boreholes BH-1 to 4
HW: Highly weathered rock
MW: Moderately weathered rock
SW: Slightly weathered rock
FR: Fresh rock

Table C1.3.7 (3) Seismic Survey Results (Grand Falls)

(C) Low Velocity Zone

Line	Distance (m)	Vp (km/sec)	
G95-A	110 - 130	3.2	
	400 - 410	2.6	
	550 - 560	3.3	near G95-3
G95-B	355 - 365	2.5	
	750 - 760	2.8	
	1,125 - 1,130	2.8-3.0	
	1,200 - 1,210	3.0	
	1,400 - 1,430	2.5	near G95-5
G95-C	265 - 295	3.8	
G95-D	No low velocity zone		
G95-E	225 - 240	2.8	
	255 - 265	2.0	
G95-F	55 - 95	3.3	near G95-11
	310 - 320	2.0	
	590 - 605	2.1	
G95-G	45 - 60	2.2	
	175 - 185	2.4	
	325 - 345	3.0	near G95-13
	555 - 565	2.6	
	670 - 690	3.0	
	890 - 905	2.8	near G95-14
	960 - 980	3.0	near G95-14
G95-H	120 - 130	3.0	
	190 - 205	4.0	
	315 - 325	2.6	near G95-3
	565 - 580	2.0	
	700 - 715	3.5	
	860 - 865	3.0-3.2	
G95-I	95 - 125	3.0	
	285 - 300	2.2	
	500 - 515	3.0	

Table C1.3.8 (1) **Rock classification for the Project**

Rock Class	Characteristics of Rock
B	Fresh and solid rock. The rock forming minerals and grains have no weathering and alteration. Joints are tight and their surfaces have no visible sign of weathering.
CH	Slightly weathered and relatively solid rock. The rock forming minerals and grains have a little weathering and/or alteration in some part. Joints are tight in general but their surfaces have sign of weathering (brown stained).
CM	Moderately weathered rock. The rock forming minerals and grains have more weathering and/or alteration than CH. Joints are partly tight and their surfaces have more sign of weathering (brown stained) than CH.
CL	Highly weathered rock. The rock forming minerals and grains have weathering and/or alteration in general. Joint surfaces have strong sign of weathering (brown stained, with clay minerals) in general.
D	Decomposed rock.

Table C1.3.8 (2) Rock classification for the Project

Rock class	Hardness	Core shape & joint interval	Weathering & alteration	Rock Classification
B	A	1	a	A1a
CH	A	1	b	A1b
	A	2, 3	a, b	A2a, A2b, A3a, A3b
	B	1, 2, 3	a, b	B1a,B1b,B2a,B2b,B3a, B3b
CM	A	4	a, b	A4a, A4b
	B	2, 3	c	B2c, B3c
	B	4	a, b	B4a, B4b
	C	1, 2	c	C1c, C2c
CL	A	5	a, b	A5a, A5b
	B	4	c	B4c
	B	5	a, b, c	B5a, B5b, B5c
	C	3, 4	c	C3c, C4c
	C	5	a, b	C5a, C5b
	D	1, 2, 3	d	D1d, D2d, D3d
D	C	5	c	C5c
	D	4, 5	d	D4d, D5d
	D	*	e	D*e
	E	*	*	E**

Note

Rating Standards for Rock Classification

i) Hardness
- A Hard rock
- B Medium hard rock
- C Weak rock
- D Very weak rock
- E Decomposed rock

ii) Core shape and joint interval
- 1 Columnar: Joint interval is around 30 cm or more.
- 2 Columnar: Joint interval is approximately 15 to 30 cm.
- 3 Mainly columnar: Joint interval is approximately 5 to 15 cm.
- 4 Short columnar and fragments: Joint interval is approximately less than 5 cm.
- 5 Mainly fragments: Heavily jointed.
- 6 Mainly sandy - clayey materials, with some fragments.

iii) Weathering and alteration
- a Fresh / no alteration
- b Slightly weathered / weak alteration
- c Moderately weathered / moderate alteration
- d Highly weathered / high alteration
- e Completely weathered / very high alteration

Table C1.3.9 Rock Classification and Rock Parameters

Rock grade	Uniaxial compress. strength (kg/cm^2)	Static modulus of elasticity (kg/cm^2)	Modulus of deformation (kg/cm^2)	Cohesion (kg/cm^2)	Internal friction angle (deg.)	Velocity of elastic wave (km/sec)
B	800 or more	80,000 or more	50,000 or more	40 or more	55-65	3.7 or more
C	800-400	80,000-40,000	50,000-20,000	40-20	40-55	3.7-3.0
D	400-200	40,000-15,000	20,000-5,000	20-10	30-45	3.0-1.5
E-F	200 or less	15,000 or less	5,000 or less	10 or less	15-38	1.5 or less

(Dr.K.Kikuchi, Mr.K.Saito & Mr.K.Kusunoki, ICOLD, May,1982)

Notes

In the above Table, each rock grade for the "medium hard rocks" (dry unconfined compression strength of "200 to 800 kgf/cm^2") means qualitatively:

B: Fresh in lithologic character. The constituent grains are quite free from secondary weathering and alteration. Fissures of joints, etc. are little distributed. The rocks as a whole are solid and hard. In this case, those close to soft rocks which have the above properties may not belong to this class, but to Grade C.

C: Fresh in lithologic character. The constituent grains are free from secondary weathering and alteration. Joints are sparsely distributed, assuring close adhesion. The rocks as a whole are almost solid and hard. In this case, those close to hard rocks may belong to Grade B.

D: Feldspars and colored minerals existing secondarily as constituent grains are mostly a little weathered and altered. The weathering is not so intensive, but since the rocks are medium hard, they give a little soft impression in absolute hardness. Joints are distributed considerably, and most of them are a little open. The joints are weathered and altered, being discolored and often hold thin layers and weathered materials. Rocks of this class have hair-like fissures to some extent. Therefore, when hit by a rock hammer, they often collapse, being separated at the hair-like fissures.

E: Constituent grains are weathered and altered, and the degree of consolidation is very low. Since the rocks are medium hard, they give considerably soft impression in absolute hardness. Joints are considerably distributed. They are open, and hold weathered materials and clay layer considerably. Rocks of this class are considerably weathered along hair-like fissures, and when hit lightly by a rock hammer, they collapse easily.

F: Constituent grains are considerably weathered and altered, and the degree of consolidation is considerably low. They are often sandy and clayey. With rocks of this class, the distribution of fissures is rather unclear.

Table C1.3.10 (1) Permeability Condition Observed in Boreholes (Grand Falls)

(A) Boreholes drilled by UN/World Bank (1987)

Hole No.	Depth (m)	Permeability (Coefficient of permeability; cm/s)	Location
BH-4	4.00 - 8.30	1.4×10^{-3}	Right bank
	8.30 - 9.30	no data	
	9.30 - 18.55	$1.6 - 2.2 \times 10^{-4}$	
	18.55 - 23.25	impermeable	
BH-1	9.05 - 13.05	4.0 x 10-5	Right bank
	13.05 - 23.50	$1.4 - 3.4 \times 10^{-4}$	
	23.50 - 30.25	$1.6 \times 10^{-5} - 1.0 \times 10^{-6}$	
BH-2	6.00 - 11.00	8.6×10^{-5}	Right bank
	13.60 - 18.60	1.0×10^{-5}	
	19.60 - 25.45	3.2×10^{-6}	
BH-3	4.00 - 8.70	1.0×10^{-4}	Right bank
	9.00 - 19.15	$1.3 - 7.1 \times 10^{-5}$	
	19.15 - 24.10	impermeable	
	24.10 - 40.45	$2.4 - 7.5 \times 10^{-5}$	
BH-5	4.75 - 15.55	impermeable	Left bank
BH-6	0.00 - 10.50	no data	Left bank

(B) Boreholes drilled in this stage (1994)

Hole No.	Depth (m)	Permeability (Lugeon)	Location
94-1	6.20 - 14.55	14.6 - 15.3	Right bank
	14.55 - 19.55	9.6	
	19.55 - 67.00	0.3 - 5.1	
	67.00 - 77.45	impermeable	
	77.45 -100.20	0.3 - 4.8	
94-2	7.10 - 12.15	2.2	Right bank
	13.50 - 42.45	0.3 - 3.6	
	42.45 - 47.40	impermeable	
	47.40 - 56.90	0.2 - 0.3	
	56.90 - 75.00	impermeable	
94-3	4.00 - 10.05	54.5	Left bank
	11.60 - 16.30	0.9	
	16.30 - 62.40	impermeable	
	62.40 - 67.60	6.0	
	67.60 - 77.05	impermeable	
	77.05 - 87.80	2.4 - 3.2	
	87.80 -100.25	impermeable	
94-4	7.00 - 11.05	96.6	Left bank
	12.00 - 51.35	impermeable	
	51.35 - 56.00	76.6	
	56.00 -101.40	impermeable	
	101.40 -111.50	17.4 - 28.2	
	111.50 -125.35	impermeable	

Table C1.3.10 (2) Permeability Condition Observed in Boreholes (Grand Falls)

(C) Boreholes drilled in this stage (1995) (1/2)

Hole No.	Depth (m)	Permeability (Lugeon)	Location
G95-1	0.00 - 6.05	no data	Left bank
	6.05 - 50.50	0-0.9	
G95-2	0.00 - 7.50	no data	Left bank
	7.50 - 17.35	10.5-54.6	
	17.35 - 30.00	0-3.3	
G95-3	0.00 - 4.15	no data	Left bank
	4.15 - 8.75	201.3	
	8.75 - 14.10	2.8	
	14.10 - 19.05	239.1	
	19.05 - 24.25	1.2	
	24.25 - 30.20	25.3	
	30.20 - 35.50	1.6	
G95-4	0.00 - 7.00	no data	Right bank
	7.00 - 12.00	36.6	
	12.00 - 14.60	no data	
	14.60 - 19.60	15.7	
	19.60 - 50.25	impermeable	
G95-5	0.00 - 12.00	no data	Right bank
	12.00 - 50.00	0-1.4	
G95-6	0.00 - 2.30	no data	Left bank
	2.30 - 8.00	1.7	
	8.00 - 13.00	77.1	
	13.00 - 80.15	0-3.6	
G95-7	0.00 - 9.40	no data	Left bank
	9.40 - 13.90	8.1	
	13.90 - 30.05	impermeable	
G95-8	0.00 - 5.50	no data	River bed
	5.50 - 15.00	7-9.8	
	15.00 - 30.50	0-3.5	
	30.50 - 35.10	19.9	
	35.10 - 50.20	impermeable	
G95-9	0.00 - 7.10	no data	Right bank
	7.10 - 12.00	8.8	
	12.00 - 13.00	no data	
	13.00 - 18.00	69.8	
	18.00 - 21.10	no data	
	21.10 - 26.00	16	
	26.00 - 30.15	impermeable	
G95-10	0.00 - 6.00	no data	Right bank
	6.00 - 11.00	42.9	
	11.00 - 13.10	no data	
	13.10 - 18.10	152.0	
	18.10 - 30.20	0-1.0	

Table C1.3.10 (3) Permeability Condition Observed in Boreholes (Grand Falls)

(C) Boreholes drilled in this stage (1995) (2/2)

Hole No.	Depth (m)	Permeability (Lugeon)	Location
G95-11	0.00 - 5.00	no data	Right bank
	5.00 - 9.00	28.3	
	9.00 - 18.00	8.5-9.5	
	18.00 - 19.00	no data	
	19.00 - 30.25	0.5-0.9	
G95-12	0.00 - 8.50	no data	Right bank
	8.50 - 19.75	32.9-42.6	
	19.75 - 30.10	0.7-3.9	
G95-13	0.00 - 7.20	no data	Right bank
	7.20 - 17.50	13.1-19.7	
	17.50 - 19.20	no data	
	19.20 - 24.70	7.6	
	24.70 - 30.10	0.9	
G95-14	0.00 - 5.70	no data	Right bank
	5.70 - 11.20	6.5	
	11.20 - 32.30	37.8-133.1	
	32.30 - 50.20	0-4.3	

Table C1.4.1(1) List of Earthquakes

Referred area : latitude -5 to 5, longitude 33.0 to 43.1

Sourced from British Geological Survey

No.	Latitude	Longitude	Depth	Magnitude	Year	Dist. (kms)	Intens. (MM)	Cornell Imm	Cornell a	Kawasumi Ij	Kawasumi a	Estava a
1	4.00	33.00	0	5.0	1906	734		0.0	0.20	0.00	0.45	0.46
2	4.00	33.00	0	5.0	1906	734		0.0	0.20	0.00	0.45	0.46
3	3.00	33.00	0	6.7	1912	667	II	1.8	0.96	0.00	0.45	2.13
4	0.50	36.50	0	7.0	1928	189	V	5.4	14.97	2.86	12.16	25.78
5	0.50	36.00	0	6.0	1928	240	III	3.3	4.19	0.29	0.63	7.75
6	5.00	33.60	0	5.0	1937	766		0.0	0.19	0.00	0.45	0.42
7	5.00	36.00	0	6.2	1937	630	I	1.2	0.72	0.00	0.45	1.59
8	-3.00	40.00	0	6.0	1938	374	II	2.2	1.73	0.00	0.45	3.54
9	-3.80	33.60	0	5.0	1951	626		0.0	0.28	0.00	0.45	0.62
10	3.00	40.00	0	5.0	1951	429		0.3	0.59	0.00	0.45	1.24
11	-4.00	35.20	0	6.0	1951	516	I	1.4	0.91	0.00	0.45	1.97
12	-5.00	35.40	33	6.5	1956	598	II	1.8	1.01	0.00	0.45	2.22
13	3.00	35.00	0	4.9	1959	496	I	0.0	0.41	0.00	0.45	0.88
14	-3.19	35.91	0	4.0	1959	397		0.0	0.31	0.00	0.45	0.64
15	-3.00	34.50	0	4.2	1959	492	I	0.0	0.24	0.00	0.45	0.51
16	-4.50	33.00	0	4.5	1959	726	I	0.0	0.14	0.00	0.45	0.31
17	-4.25	34.00	0	6.1	1959	625	I	1.1	0.67	0.00	0.45	1.49
18	-3.00	35.00	0	3.0	1964	449		0.0	0.11	0.00	0.45	0.23
19	-4.00	34.00	0	3.0	1964	606		0.0	0.06	0.00	0.45	0.13
20	-3.40	35.00	0	3.0	1964	480		0.0	0.10	0.00	0.45	0.20
21	-3.88	35.06	49	6.7	1964	516	II	2.4	1.58	0.00	0.45	3.41
22	-5.00	35.00	0	3.0	1965	620		0.0	0.06	0.00	0.45	0.13
23	4.00	35.50	0	3.0	1965	554		0.0	0.07	0.00	0.45	0.16
24	-4.79	34.92	15	4.3	1965	606	I	0.0	0.17	0.00	0.45	0.37
25	-4.83	35.00	12	3.0	1965	605		0.0	0.06	0.00	0.45	0.13
26	-4.10	35.10	24	4.9	1965	532	I	0.0	0.35	0.00	0.45	0.77
27	-5.00	35.00	0	3.0	1966	620		0.0	0.06	0.00	0.45	0.13
28	-3.93	35.75	0	3.0	1966	475		0.0	0.10	0.00	0.45	0.21
29	-4.00	35.00	0	3.0	1966	530		0.0	0.08	0.00	0.45	0.17
30	-4.00	38.00	0	3.0	1966	412		0.0	0.13	0.00	0.45	0.27
31	-4.50	35.40	0	3.0	1966	550		0.0	0.07	0.00	0.45	0.16
32	-4.00	35.00	0	3.0	1966	530		0.0	0.08	0.00	0.45	0.17
33	-4.00	35.00	0	3.0	1966	530		0.0	0.08	0.00	0.45	0.17
34	-4.00	33.00	0	3.0	1966	692		0.0	0.05	0.00	0.45	0.10
35	-4.70	41.40	0	3.0	1966	619		0.0	0.06	0.00	0.45	0.13
36	-3.54	35.35	0	3.0	1966	466		0.0	0.10	0.00	0.45	0.22
37	-4.00	36.00	0	3.0	1966	468		0.0	0.10	0.00	0.45	0.21
38	-1.00	35.00	0	3.0	1966	343		0.0	0.19	0.00	0.45	0.38
39	-3.60	35.60	0	3.0	1966	454		0.0	0.11	0.00	0.45	0.23
40	-3.90	35.40	0	3.0	1966	494		0.0	0.09	0.00	0.45	0.19
41	-5.00	35.00	0	3.0	1966	620		0.0	0.06	0.00	0.45	0.13
42	-4.00	35.00	0	3.0	1966	530		0.0	0.08	0.00	0.45	0.17
43	-5.00	35.00	0	3.0	1966	620		0.0	0.06	0.00	0.45	0.13
44	-4.00	35.00	0	3.0	1966	530		0.0	0.08	0.00	0.45	0.17
45	-4.00	36.00	0	3.0	1966	468		0.0	0.10	0.00	0.45	0.21
46	-3.90	35.53	33	1.8	1966	486	I	0.0	0.04	0.00	0.45	0.08
47	-4.00	36.00	0	3.0	1966	468		0.0	0.10	0.00	0.45	0.21
48	-3.00	36.00	0	3.0	1966	374		0.0	0.16	0.00	0.45	0.32
49	-4.00	34.50	0	3.0	1966	567		0.0	0.07	0.00	0.45	0.15
50	-3.30	35.40	0	3.0	1966	442		0.0	0.11	0.00	0.45	0.24
51	-4.08	33.63	33	2.0	1966	643	I	0.0	0.02	0.00	0.45	0.05
52	-5.00	33.00	0	3.0	1966	763		0.0	0.04	0.00	0.45	0.09
53	0.70	36.20	0	3.0	1966	229		0.0	0.42	0.00	0.45	0.76
54	0.50	36.50	0	3.0	1966	189		0.0	0.61	0.00	0.45	1.05
55	-1.60	33.00	0	3.0	1966	575		0.0	0.07	0.00	0.45	0.15
56	-4.00	34.00	0	3.0	1966	606		0.0	0.06	0.00	0.45	0.13
57	-4.50	35.40	0	3.0	1966	550		0.0	0.07	0.00	0.45	0.16
58	-5.00	36.00	0	3.0	1966	568		0.0	0.07	0.00	0.45	0.15
59	-5.00	36.00	0	3.0	1967	568		0.0	0.07	0.00	0.45	0.15
60	-4.00	36.00	0	3.0	1967	468		0.0	0.10	0.00	0.45	0.21

Table C1.4.1(2) List of Earthquakes

Referred area : latitude -5 to 5, longitude 33.0 to 43.1

Sourced from British Geological Survey

No.	Latitude	Longitude	Depth	Magnitude	Year	Dist. (kms)	Intens. (MM)	Cornell Imm	Cornell a	Kawasumi Ij	Kawasumi a	Estava a
61	-5.00	36.00	0	3.0	1967	568		0.0	0.07	0.00	0.45	0.15
62	-5.00	35.00	0	3.0	1967	620		0.0	0.06	0.00	0.45	0.13
63	-4.70	34.70	0	3.0	1967	612		0.0	0.06	0.00	0.45	0.13
64	-3.00	36.00	0	3.0	1967	374		0.0	0.16	0.00	0.45	0.32
65	4.10	35.40	0	3.0	1967	569		0.0	0.07	0.00	0.45	0.15
66	-4.20	37.00	0	3.0	1967	448		0.0	0.11	0.00	0.45	0.23
67	-3.80	36.50	0	3.0	1967	424		0.0	0.12	0.00	0.45	0.26
68	-3.00	37.00	0	3.0	1967	320		0.0	0.21	0.00	0.45	0.43
69	-3.00	36.00	0	3.0	1967	374		0.0	0.16	0.00	0.45	0.32
70	-3.99	35.74	0	3.0	1967	482		0.0	0.09	0.00	0.45	0.20
71	-3.32	38.19	33	4.9	1967	337	I	0.8	0.88	0.00	0.45	1.76
72	3.00	33.00	0	3.0	1967	667		0.0	0.05	0.00	0.45	0.11
73	-4.00	36.00	0	3.0	1967	468		0.0	0.10	0.00	0.45	0.21
74	1.30	34.00	0	3.0	1967	480		0.0	0.10	0.00	0.45	0.20
75	1.30	34.00	0	3.0	1967	480		0.0	0.10	0.00	0.45	0.20
76	1.30	34.00	0	3.0	1967	480		0.0	0.10	0.00	0.45	0.20
77	1.30	34.00	0	3.0	1967	480		0.0	0.10	0.00	0.45	0.20
78	1.30	34.00	0	3.0	1967	480		0.0	0.10	0.00	0.45	0.20
79	-2.70	40.20	0	3.0	1968	362		0.0	0.17	0.00	0.45	0.34
80	5.00	34.00	0	3.0	1968	739		0.0	0.04	0.00	0.45	0.09
81	-5.00	38.00	0	3.0	1968	523		0.0	0.08	0.00	0.45	0.17
82	-1.00	33.80	0	3.0	1968	474		0.0	0.10	0.00	0.45	0.21
83	-1.00	33.80	0	3.0	1968	474		0.0	0.10	0.00	0.45	0.21
84	-0.61	34.40	0	3.0	1968	402		0.0	0.14	0.00	0.45	0.28
85	-0.50	34.00	0	3.0	1968	446		0.0	0.11	0.00	0.45	0.23
86	-0.61	34.42	13	3.0	1968	400		0.0	0.14	0.00	0.45	0.28
87	-0.58	34.38	41	3.0	1968	404		0.0	0.13	0.00	0.45	0.28
88	-0.50	34.20	0	3.0	1968	424		0.0	0.12	0.00	0.45	0.26
89	-0.50	34.30	0	3.0	1968	412		0.0	0.13	0.00	0.45	0.27
90	-0.60	34.37	0	3.0	1968	405		0.0	0.13	0.00	0.45	0.28
91	-0.30	34.44	0	3.0	1968	396		0.0	0.14	0.00	0.45	0.29
92	-4.67	34.96	33	4.5	1968	592	I	0.0	0.21	0.00	0.45	0.46
93	-0.66	34.41	0	3.0	1968	402		0.0	0.14	0.00	0.45	0.28
94	-4.00	33.00	0	3.0	1968	692		0.0	0.05	0.00	0.45	0.10
95	-0.69	34.40	18	3.0	1968	403		0.0	0.14	0.00	0.45	0.28
96	-3.17	37.10	33	3.7	1968	335	I	0.0	0.34	0.00	0.45	0.68
97	-3.30	33.50	0	3.0	1968	602		0.0	0.06	0.00	0.45	0.13
98	-3.80	36.60	0	3.0	1968	420		0.0	0.12	0.00	0.45	0.26
99	-4.00	35.00	0	3.0	1968	530		0.0	0.08	0.00	0.45	0.17
100	-3.90	36.50	0	3.0	1968	434		0.0	0.12	0.00	0.45	0.25
101	-3.80	35.30	0	3.0	1968	492		0.0	0.09	0.00	0.45	0.19
102	2.21	33.95	66	3.0	1968	530		0.0	0.08	0.00	0.45	0.17
103	-4.81	34.98	33	2.0	1968	604	I	0.0	0.03	0.00	0.45	0.06
104	-1.26	33.35	30	1.0	1968	528	I	0.0	0.02	0.00	0.45	0.03
105	-4.28	35.07	0	3.0	1968	550		0.0	0.07	0.00	0.45	0.16
106	-4.00	33.00	0	3.0	1968	692		0.0	0.05	0.00	0.45	0.10
107	-4.63	35.66	0	3.0	1968	548		0.0	0.07	0.00	0.45	0.16
108	3.30	35.50	0	3.0	1968	488		0.0	0.09	0.00	0.45	0.20
109	-3.81	35.63	34	3.7	1969	471	I	0.0	0.17	0.00	0.45	0.37
110	-3.62	35.80	33	3.6	1969	443	I	0.0	0.18	0.00	0.45	0.38
111	-3.20	36.44	33	4.1	1969	367	I	0.0	0.39	0.00	0.45	0.80
112	-4.48	35.24	0	3.6	1969	557	I	0.0	0.11	0.00	0.45	0.25
113	-3.84	35.69	33	3.9	1969	470	I	0.0	0.20	0.00	0.45	0.43
114	-3.90	36.00	33	3.8	1969	458	I	0.0	0.20	0.00	0.45	0.42
115	-4.30	36.10	0	3.8	1969	493	I	0.0	0.17	0.00	0.45	0.37
116	-3.90	35.70	0	3.7	1969	475	I	0.0	0.17	0.00	0.45	0.36
117	-3.00	33.60	0	3.5	1969	574	I	0.0	0.10	0.00	0.45	0.22
118	-4.50	33.00	0	2.9	1969	726	I	0.0	0.04	0.00	0.45	0.09
119	-4.14	35.40	0	2.6	1969	516	I	0.0	0.06	0.00	0.45	0.13
120	-1.25	34.02	0	4.0	1969	455	I	0.0	0.24	0.00	0.45	0.50

Table C1.4.1(3) List of Earthquakes

Referred area : latitude -5 to 5, longitude 33.0 to 43.1 **Sourced from British Geological Survey**

No.	Latitude	Longitude	Depth	Magnitude	Year	Dist. (kms)	Intens. (MM)	Cornell Imm	a	Kawasumi Ij	a	Estava a
121	-3.28	36.00	33	2.6	1969	399	I	0.0	0.10	0.00	0.45	0.21
122	-4.90	38.40	0	3.0	1969	514	I	0.0	0.08	0.00	0.45	0.18
123	-4.64	38.40	0	3.5	1970	485	I	0.0	0.14	0.00	0.45	0.30
124	-3.70	35.60	0	3.5	1970	463	I	0.0	0.15	0.00	0.45	0.32
125	-2.50	40.10	0	3.5	1970	339	I	0.0	0.29	0.00	0.45	0.57
126	-4.69	36.79	0	3.5	1971	507	I	0.0	0.13	0.00	0.45	0.27
127	-3.44	35.18	0	3.5	1971	470	I	0.0	0.15	0.00	0.45	0.32
128	-3.64	35.49	0	3.6	1971	465	I	0.0	0.16	0.00	0.45	0.35
129	4.30	33.60	0	3.0	1971	708		0.0	0.04	0.00	0.45	0.10
130	-4.00	33.30	0	3.7	1972	665	I	0.0	0.09	0.00	0.45	0.19
131	-4.50	34.14	33	4.5	1972	635	I	0.0	0.18	0.00	0.45	0.40
132	-4.17	34.41	0	4.1	1972	587	I	0.0	0.15	0.00	0.45	0.34
133	-4.10	35.51	0	4.5	1972	506	I	0.0	0.29	0.00	0.45	0.61
134	-3.44	35.97	0	3.7	1972	416	I	0.0	0.22	0.00	0.45	0.46
135	-0.29	35.11	0	4.1	1972	322	I	0.0	0.51	0.00	0.45	1.01
136	-3.27	36.66	33	4.1	1972	363	I	0.0	0.40	0.00	0.45	0.81
137	-3.57	35.80	0	3.9	1972	439	I	0.0	0.23	0.00	0.45	0.49
138	-3.41	36.48	0	4.1	1972	385	I	0.0	0.36	0.00	0.45	0.74
139	-3.50	36.41	0	3.8	1972	398	I	0.0	0.26	0.00	0.45	0.54
140	-3.59	35.96	0	4.0	1972	431	I	0.0	0.26	0.00	0.45	0.55
141	-3.30	38.86	0	4.0	1973	347	I	0.0	0.41	0.00	0.45	0.82
142	-4.93	35.96	0	3.8	1973	563	I	0.0	0.13	0.00	0.45	0.29
143	-3.04	35.56	33	2.2	1973	408	I	0.0	0.07	0.00	0.45	0.14
144	-4.85	34.44	0	3.7	1973	643	I	0.0	0.09	0.00	0.45	0.21
145	-4.90	34.90	0	3.7	1973	617	I	0.0	0.10	0.00	0.45	0.22
146	-3.31	35.48	0	3.5	1973	437	I	0.0	0.17	0.00	0.45	0.36
147	-4.50	34.30	0	3.4	1974	623	I	0.0	0.08	0.00	0.45	0.17
148	-3.61	34.72	0	3.7	1974	519	I	0.0	0.14	0.00	0.45	0.31
149	-3.94	33.30	0	4.3	1974	661	I	0.0	0.14	0.00	0.45	0.32
150	-3.00	33.00	0	4.0	1974	632	I	0.0	0.12	0.00	0.45	0.27
151	-4.23	33.38	0	3.9	1975	675	I	0.0	0.10	0.00	0.45	0.22
152	-4.12	35.23	0	4.2	1975	525	I	0.0	0.21	0.00	0.45	0.45
153	-2.80	37.50	0	4.9	1975	284	I	1.2	1.24	0.00	0.45	2.40
154	-2.35	38.76	0	4.1	1975	243	I	0.4	0.89	0.00	0.45	1.66
155	-4.35	35.75	32	4.9	1975	516	I	0.0	0.38	0.00	0.45	0.81
156	-2.64	38.28	0	4.1	1975	262	I	0.2	0.77	0.00	0.45	1.46
157	-3.91	35.62	0	3.9	1975	481	I	0.0	0.20	0.00	0.45	0.42
158	-2.39	36.15	0	3.6	1975	311	I	0.0	0.37	0.00	0.45	0.72
159	-2.74	37.01	0	4.2	1975	293	I	0.1	0.67	0.00	0.45	1.30
160	-2.71	37.86	0	4.1	1975	269	I	0.2	0.73	0.00	0.45	1.39
161	-3.41	36.47	0	3.9	1975	386	I	0.0	0.30	0.00	0.45	0.62
162	-3.61	37.15	0	4.1	1975	380	I	0.0	0.37	0.00	0.45	0.75
163	-2.44	38.41	0	3.9	1976	243	I	0.1	0.76	0.00	0.45	1.41
164	-3.10	37.20	0	3.7	1976	324	I	0.0	0.37	0.00	0.45	0.73
165	-2.93	37.46	25	4.4	1976	299	I	0.3	0.75	0.00	0.45	1.46
166	-2.81	37.34	0	4.0	1976	289	I	0.0	0.58	0.00	0.45	1.13
167	-2.78	36.97	40	3.0	1976	299	I	0.0	0.24	0.00	0.45	0.47
168	-2.85	37.38	0	4.0	1976	292	I	0.0	0.57	0.00	0.45	1.11
169	-3.30	36.30	0	3.9	1976	384	I	0.0	0.31	0.00	0.45	0.63
170	-2.66	36.93	0	3.7	1976	288	I	0.0	0.46	0.00	0.45	0.90
171	-3.00	37.00	0	3.6	1977	320	I	0.0	0.35	0.00	0.45	0.69
172	-2.80	37.06	0	3.8	1977	297	I	0.0	0.47	0.00	0.45	0.92
173	-4.25	36.09	0	3.6	1977	488	I	0.0	0.15	0.00	0.45	0.32
174	-4.79	34.91	0	5.6	1977	606	I	0.4	0.48	0.00	0.45	1.06
175	-4.91	34.83	0	2.8	1978	623	I	0.0	0.05	0.00	0.45	0.11
176	-5.00	34.30	0	4.0	1978	666	I	0.0	0.11	0.00	0.45	0.25
177	-3.73	33.63	0	4.3	1978	618	I	0.0	0.16	0.00	0.45	0.36
178	-1.71	37.15	25	4.3	1978	183	I	1.4	1.81	0.00	0.45	3.09
179	-3.59	34.53	0	4.1	1978	532	I	0.0	0.19	0.00	0.45	0.41
180	2.96	36.22	0	3.9	1978	413	I	0.0	0.26	0.00	0.45	0.55

Table C1.4.1(4) List of Earthquakes

Referred area : latitude -5 to 5, longitude 33.0 to 43.1

Sourced from British Geological Survey

No.	Latitude	Longitude	Depth	Magnitude	Year	Dist. (kms)	Intens. (MM)	Cornell Imm	Cornell a	Kawasumi Ij	Kawasumi a	Estava a
181	-4.86	38.44	0	4.1	1978	510	I	0.0	0.20	0.00	0.45	0.44
182	-3.00	36.00	0	3.9	1979	374	I	0.0	0.32	0.00	0.45	0.66
183	-4.18	34.53	19	2.4	1979	579	I	0.0	0.04	0.00	0.45	0.09
184	-4.70	39.00	0	3.6	1980	502	I	0.0	0.14	0.00	0.45	0.30
185	-3.70	33.60	0	3.6	1980	619	I	0.0	0.09	0.00	0.45	0.21
186	-3.78	35.42	0	3.5	1980	482	I	0.0	0.14	0.00	0.45	0.30
187	-4.16	34.68	33	2.2	1980	567	I	0.0	0.04	0.00	0.45	0.08
188	-3.85	36.00	33	2.4	1980	453	I	0.0	0.07	0.00	0.45	0.14
189	-2.13	39.75	0	3.8	1980	282	I	0.0	0.52	0.00	0.45	1.01
190	-4.74	34.64	10	2.2	1982	620	I	0.0	0.03	0.00	0.45	0.07
191	-4.20	34.50	0	3.0	1983	583		0.0	0.06	0.00	0.45	0.14
192	-3.97	35.66	10	3.5	1983	484	I	0.0	0.14	0.00	0.45	0.30
193	-4.43	35.39	10	3.0	1983	544		0.0	0.07	0.00	0.45	0.16
194	-3.39	36.85	10	3.0	1983	367		0.0	0.16	0.00	0.45	0.33
195	-4.31	35.25	19	4.7	1983	541	I	0.0	0.29	0.00	0.45	0.64
196	-4.40	35.23	0	3.0	1983	551		0.0	0.07	0.00	0.45	0.16
197	-4.20	37.79	14	5.2	1983	435	I	0.6	0.68	0.00	0.45	1.42
198	-4.20	37.80	0	3.5	1983	435	I	0.0	0.17	0.00	0.45	0.36
199	-4.20	37.80	0	3.5	1983	435	I	0.0	0.17	0.00	0.45	0.36
200	-4.70	34.32	0	3.0	1983	638		0.0	0.05	0.00	0.45	0.12
201	-3.00	35.81	10	2.6	1983	387	I	0.0	0.11	0.00	0.45	0.22
202	1.05	36.40	0	3.0	1984	233		0.0	0.40	0.00	0.45	0.74
203	-3.91	37.87	10	3.9	1984	402	I	0.0	0.28	0.00	0.45	0.58
204	-4.18	35.87	0	3.0	1984	493		0.0	0.09	0.00	0.45	0.19
205	0.50	33.70	0	3.0	1985	487		0.0	0.09	0.00	0.45	0.20
206	4.70	33.19	10	3.2	1985	772	I	0.0	0.04	0.00	0.45	0.10
207	-4.10	33.65	0	3.0	1985	643		0.0	0.05	0.00	0.45	0.12
208	-0.86	34.02	10	3.0	1986	447		0.0	0.11	0.00	0.45	0.23
209	-4.50	33.36	10	3.0	1986	696		0.0	0.05	0.00	0.45	0.10
210	-4.18	37.68	10	3.9	1986	433	I	0.0	0.24	0.00	0.45	0.51
211	-3.28	36.21	33	3.0	1986	387		0.0	0.15	0.00	0.45	0.30
212	-4.60	36.60	0	3.9	1986	503	I	0.0	0.18	0.00	0.45	0.38
213	-4.62	35.77	10	3.0	1987	541		0.0	0.08	0.00	0.45	0.16
214	-1.70	33.50	10	2.6	1987	525	I	0.0	0.06	0.00	0.45	0.13
215	-3.69	34.43	0	3.0	1987	548		0.0	0.07	0.00	0.45	0.16
216	-0.92	35.85	10	4.0	1987	249	I	0.2	0.79	0.00	0.45	1.47
217	-4.80	35.90	0	3.6	1987	553	I	0.0	0.12	0.00	0.45	0.25
218	-0.66	34.61	10	3.0	1987	379		0.0	0.15	0.00	0.45	0.31
219	4.42	35.61	10	2.8	1988	589	I	0.0	0.05	0.00	0.45	0.12
220	-4.16	33.60	10	3.9	1988	651	I	0.0	0.11	0.00	0.45	0.24
221	-1.60	33.00	10	2.7	1988	575	I	0.0	0.05	0.00	0.45	0.11
222	-3.87	35.82	10	3.2	1988	466	I	0.0	0.12	0.00	0.45	0.25
223	-1.89	33.94	10	3.0	1988	485		0.0	0.09	0.00	0.45	0.20
224	-3.78	34.09	10	3.5	1988	582	I	0.0	0.10	0.00	0.45	0.21
225	-4.75	35.80	10	3.9	1988	552	I	0.0	0.15	0.00	0.45	0.32
226	4.42	35.61	10	2.8	1988	589	I	0.0	0.05	0.00	0.45	0.12
227	-4.16	33.60	10	3.9	1988	651	I	0.0	0.11	0.00	0.45	0.24
228	-1.60	33.00	10	2.7	1988	575	I	0.0	0.05	0.00	0.45	0.11
229	-3.87	35.82	10	3.2	1988	466	I	0.0	0.12	0.00	0.45	0.25
230	-1.89	33.94	10	3.0	1988	485		0.0	0.09	0.00	0.45	0.20
231	-3.78	34.09	10	3.5	1988	582	I	0.0	0.10	0.00	0.45	0.21
232	-4.75	35.80	10	3.9	1988	552	I	0.0	0.15	0.00	0.45	0.32
233	-1.06	33.46	10	3.0	1989	512		0.0	0.08	0.00	0.45	0.18
234	-3.74	34.22	10	3.0	1989	569		0.0	0.07	0.00	0.45	0.15
235	-3.70	35.70	10	3.8	1989	457	I	0.0	0.20	0.00	0.45	0.42
236	-3.43	34.50	10	3.7	1989	522	I	0.0	0.14	0.00	0.45	0.31
237	0.04	38.61	10	4.3	1989	78	III	3.5	9.47	0.00	0.45	11.08
238	0.18	38.56	10	4.3	1989	82	III	3.3	8.63	0.00	0.45	10.37
239	-4.03	39.92	10	5.2	1990	467	I	0.4	0.59	0.00	0.45	1.25
240	-2.90	35.78	10	3.0	1990	381	I	0.0	0.15	0.00	0.45	0.31

Table C1.4.1(5) List of Earthquakes

Referred area : latitude -5 to 5, longitude 33.0 to 43.1 **Sourced from British Geological Survey**

No.	Latitude	Longitude	Depth	Magnitude	Year	Dist. (kms)	Intens. (MM)	Cornell Imm	a	Kawasumi Ij	a	Estava a
241	-2.95	35.95	38	4.5	1990	373	I	0.0	0.52	0.00	0.45	1.06
242	-4.30	39.81	10	2.4	1990	489	I	0.0	0.06	0.00	0.45	0.12
243	-3.20	35.78	5	4.8	1990	406	I	0.2	0.56	0.00	0.45	1.17
244	-3.10	35.86	5	5.2	1990	392	I	0.9	0.83	0.00	0.45	1.72
245	-3.20	35.80	10	3.0	1990	405		0.0	0.13	0.00	0.45	0.28
246	-4.30	33.80	10	3.0	1990	645		0.0	0.05	0.00	0.45	0.12
247	4.83	33.63	10	3.9	1990	750	I	0.0	0.08	0.00	0.45	0.18
248	-2.93	36.01	10	4.1	1990	367	I	0.0	0.39	0.00	0.45	0.80
249	-3.50	34.20	10	3.0	1990	553		0.0	0.07	0.00	0.45	0.16
250	-3.90	33.88	0	4.1	1990	609	I	0.0	0.14	0.00	0.45	0.32
251	-3.02	35.40	33	3.5	1990	419	I	0.0	0.19	0.00	0.45	0.39
252	-4.37	33.71	10	3.0	1990	658		0.0	0.05	0.00	0.45	0.11
253	-3.19	38.17	10	3.0	1991	322	I	0.0	0.21	0.00	0.45	0.42
254	-3.97	35.81	10	4.5	1991	476	I	0.0	0.32	0.00	0.45	0.69
255	-3.84	35.63	28	5.3	1993	474	I	0.5	0.61	0.00	0.45	1.31
256	-3.97	35.85	33	3.2	1993	473	I	0.0	0.11	0.00	0.45	0.24
257	-3.99	34.05	33	4.9	1993	601	I	0.0	0.28	0.00	0.45	0.61
258	4.52	35.03	10	4.4	1994	630	I	0.0	0.17	0.00	0.45	0.38

Table C1.4.2 List of Selected Earthquakes for the Estimation of Maximum Acceleration

Sourced from British Geological Survey

Latitude	Longitude	Depth (kms)	Magnitude	Year	Dist. (kms)	Intens. (MM)	Cornell Imm	a
0.5	36.5	0	7	1928	189	V	5.4	15.0
0.04	38.6	10	4.3	1989	78	III	3.5	9.5
0.18	38.6	10	4.3	1989	82	III	3.3	8.6
0.5	36.0	0	6	1928	240	III	3.3	4.2
-3.88	35.1	49	6.7	1964	516	II	2.4	1.6
-3	40.0	0	6	1938	374	II	2.2	1.7
3	33.0	0	6.7	1912	667	II	1.8	1.0
-5	35.4	33	6.5	1956	598	II	1.8	1.0
-1.71	37.2	25	4.3	1978	183	I	1.4	1.8
-4	35.2	0	6	1951	516	I	1.4	0.9
-2.8	37.5	0	4.9	1975	284	I	1.2	1.2
5	36.0	0	6.2	1937	630	I	1.2	0.7
-4.25	34.0	0	6.1	1959	625	I	1.1	0.7
-3.1	35.9	5	5.2	1990	392	I	0.9	0.8
-3.32	38.2	33	4.9	1967	337	1	0.8	0.9
-4.2	37.8	14	5.2	1983	435	I	0.6	0.7
-3.84	35.6	28	5.3	1993	474	I	0.5	0.6
-4.03	39.9	10	5.2	1990	467	I	0.4	0.6
-2.35	38.8	0	4.1	1975	243	I	0.4	0.9
-4.79	34.9	0	5.6	1977	606	1	0.4	0.5
3	40.0	0	5	1951	429		0.3	0.6
-2.93	37.5	25	4.4	1976	299	I	0.3	0.7
-2.64	38.3	0	4.1	1975	262	I	0.2	0.8
-0.92	35.9	10	4	1987	249	I	0.2	0.8
-3.2	35.8	5	4.8	1990	406	1	0.2	0.6
-2.71	37.9	0	4.1	1975	269	I	0.2	0.7
-2.44	38.4	0	3.9	1976	243	I	0.1	0.8
-2.74	37.0	0	4.2	1975	293	I	0.1	0.7

Imm : Intensity in Modified Mercalli Scale, estimated according to Cornell.
a: Acceleration, estimated according to Cornel.

Table C1.4.3 Estimation of Maximum Acceleration by Cornell's method

Intensity Imm		Frequency in 89 years	Frequency in 100 years	Cumulative number for 100yrs N	Frequency in 200 years	Cumulative number for 200yrs N
0	(0-0.5)	12	13.48	31.46	26.97	62.92
1	(0.5-1.5)	8	8.99	17.98	17.98	35.96
2	(1.5-2.5)	4	4.49	8.99	8.99	17.98
3	(2.5-3.5)	3	3.37	4.49	6.74	8.99
4	(3.5-4.5)	0	0.00	1.12	0.00	2.25
5	(4.5-5.5)	1	1.12	1.12	2.25	2.25
6	(5.5-6.5)	0	0.00	0.00	0.00	0.00
7	(6.5-7.5)	0	0.00	0.00	0.00	0.00
8	(7.5-8.5)	0	0.00	0.00	0.00	0.00
9	(8.5-9.5)	0	0.00	0.00	0.00	0.00

For 100 years (Refer to Graph 1)

Log(N) = -0.3184(Imm)+1.5383

Expected Maximum Intensity for 100 years

Imm = 4.83

Maximum Acceleration in a Return Period of 100 years

Log(a) = Imm/3 - 0.5

a = 13 gal

= 0.01 g

For 200 years (Refer to Graph 2)

Log(N) = -0.3184(Imm)+1.8394

Expected Maximum Intensity for 100 years

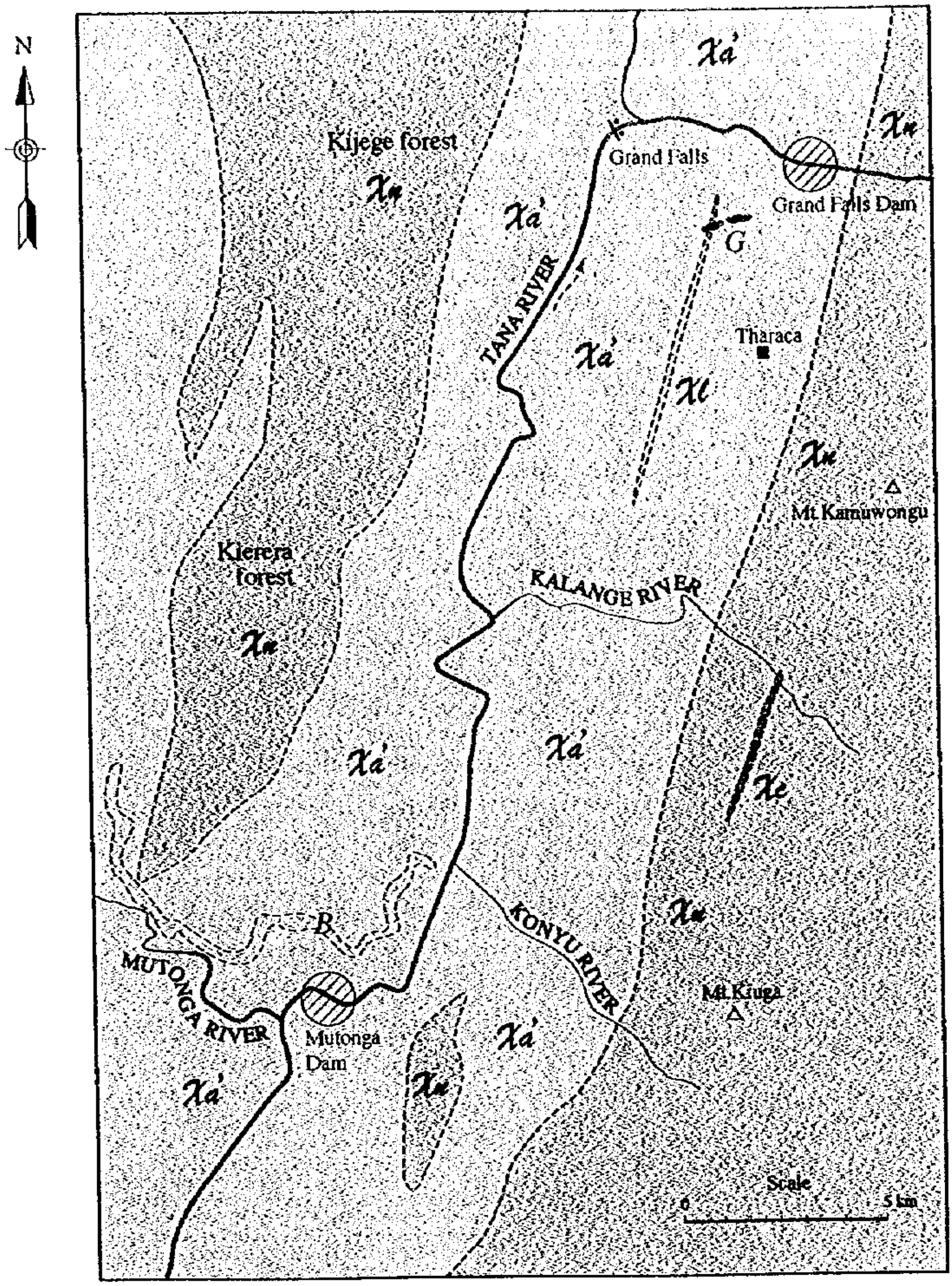
Imm = 5.78

Maximum Acceleration in a Return Period of 100 years

Log(a) = Imm/3 - 0.5

a = 27 gal

= 0.03 g



From * Geology of the North Kitui Area.
Geological Survey of Kenya.
Report No.33, 1/125,000.
* A Geological Reconnaissance of the country between Embu and Meru.
Geological Survey of Kenya
Report No.17, 1/125,000.

LEGEND

- B : Basalt (Pleistocene?)
- ■ : Granite (Archaean?)
- Xg : Granitic gneiss
- Xa : Semi-pelitic gneiss
- Xl : Crystaline limestone
- Xc : Calc-silicate gneiss
- (Granitic gneiss, Semi-pelitic gneiss, Crystaline limestone, Calc-silicate gneiss: Kenya Basement System (Archaean))
- - - Geological boundary

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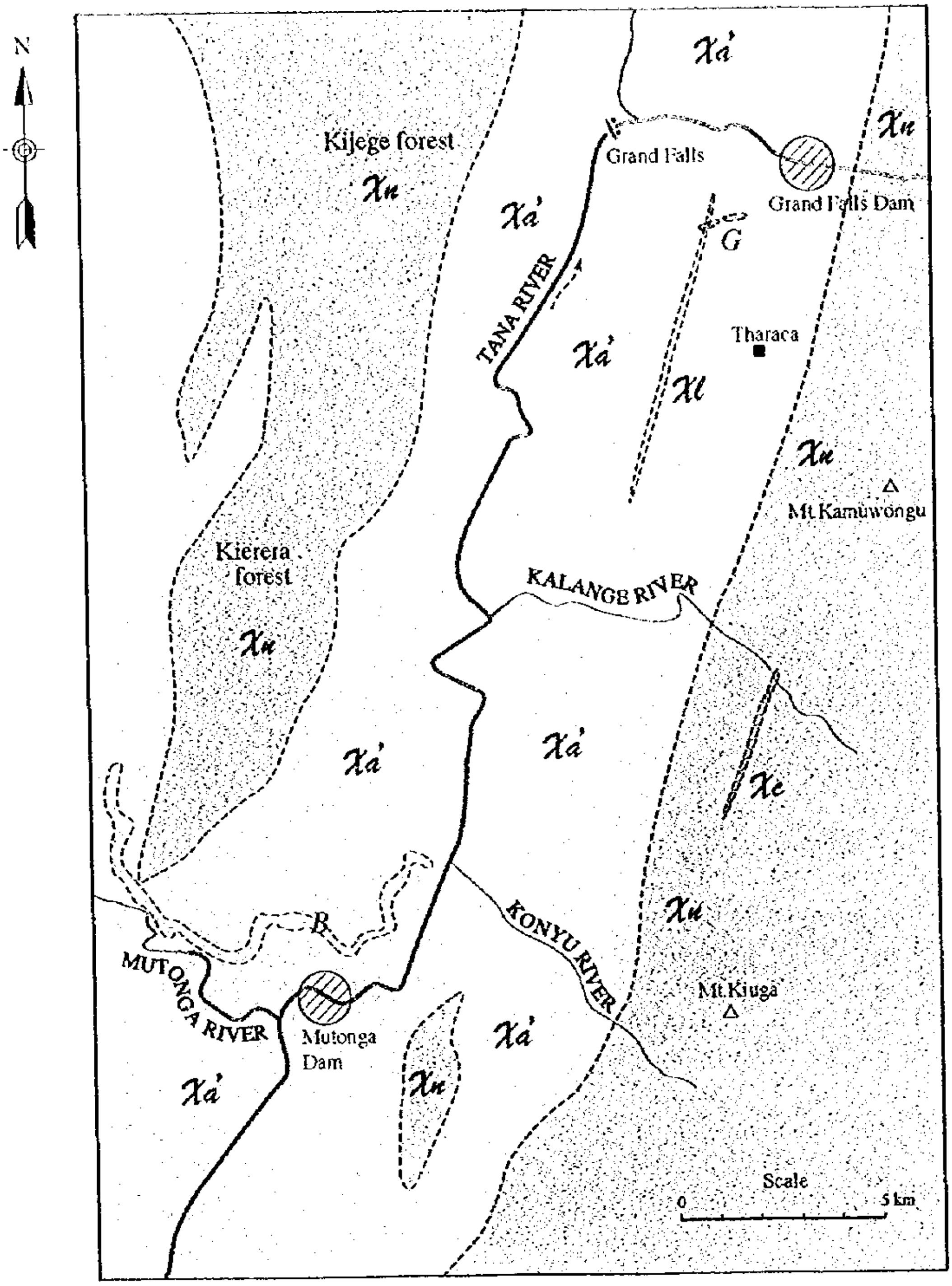


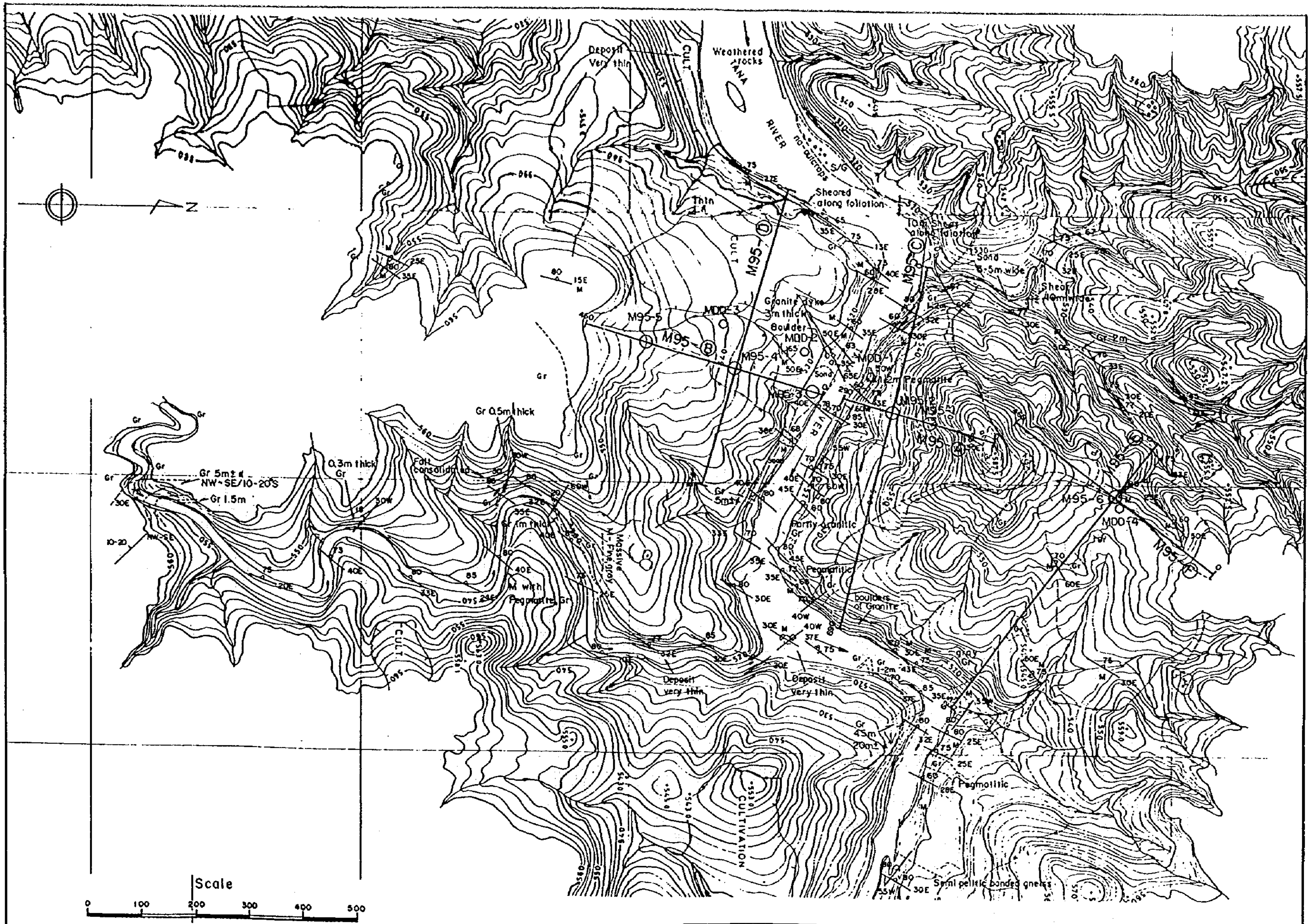
From * Geology of the North Kitui Area. Geological Survey of Kenya. Report No.33, 1/125,000.
* A Geological Reconnaissance of the country between Embu and Meru. Geological Survey of Kenya Report No.17, 1/125,000.

LEGEND

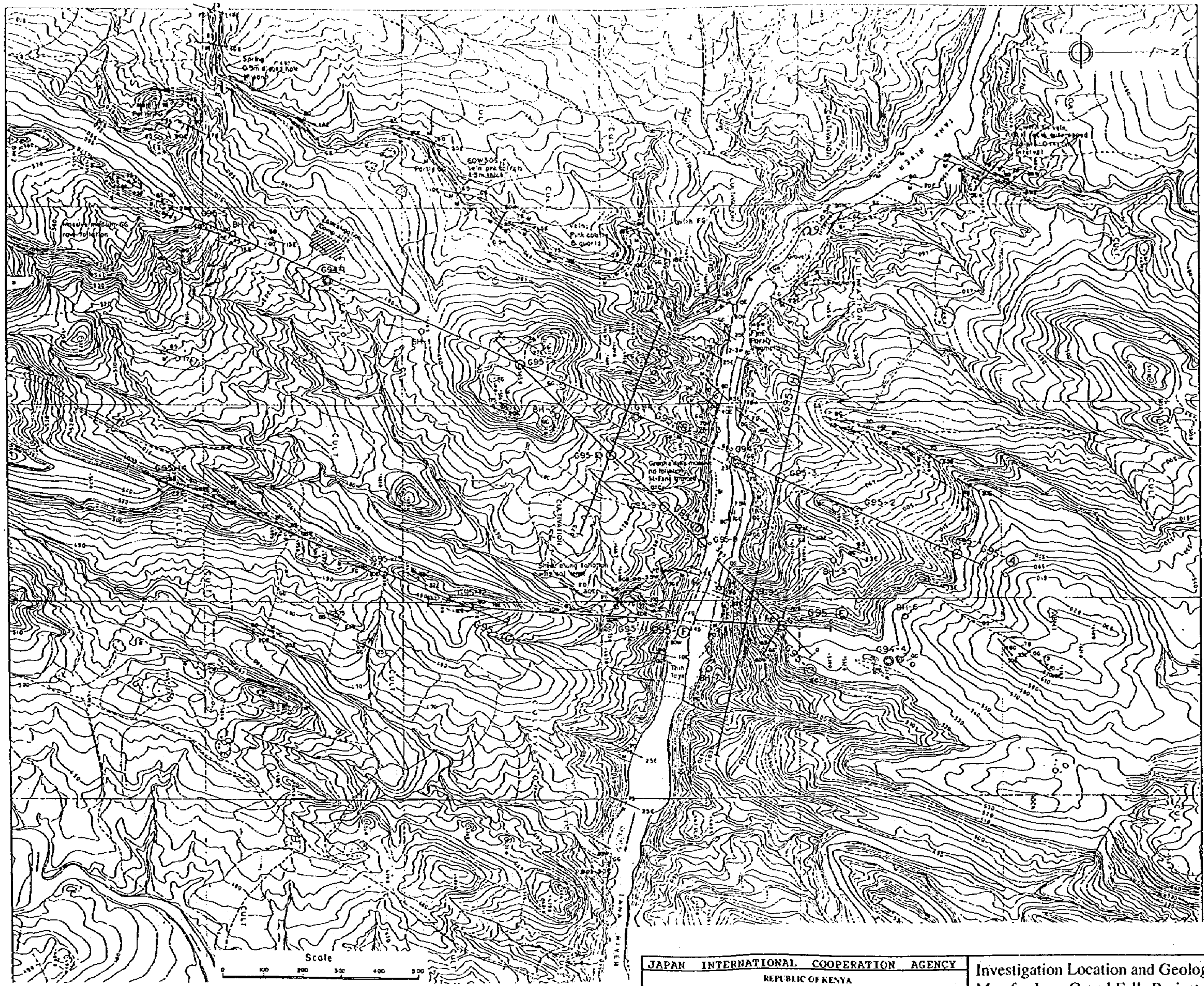
- B : Basalt (Pleistocene?)
- G : Granite (Archaean?)
- Xn : Granitic gneiss
- Xa' : Semi-pelitic gneiss
- Xl : Crystaline limestone
- Xe : Calc-silicate gneiss
- Geological boundary

(Xn, Xa', Xl, Xe: Kenya Basement System (Archaean))

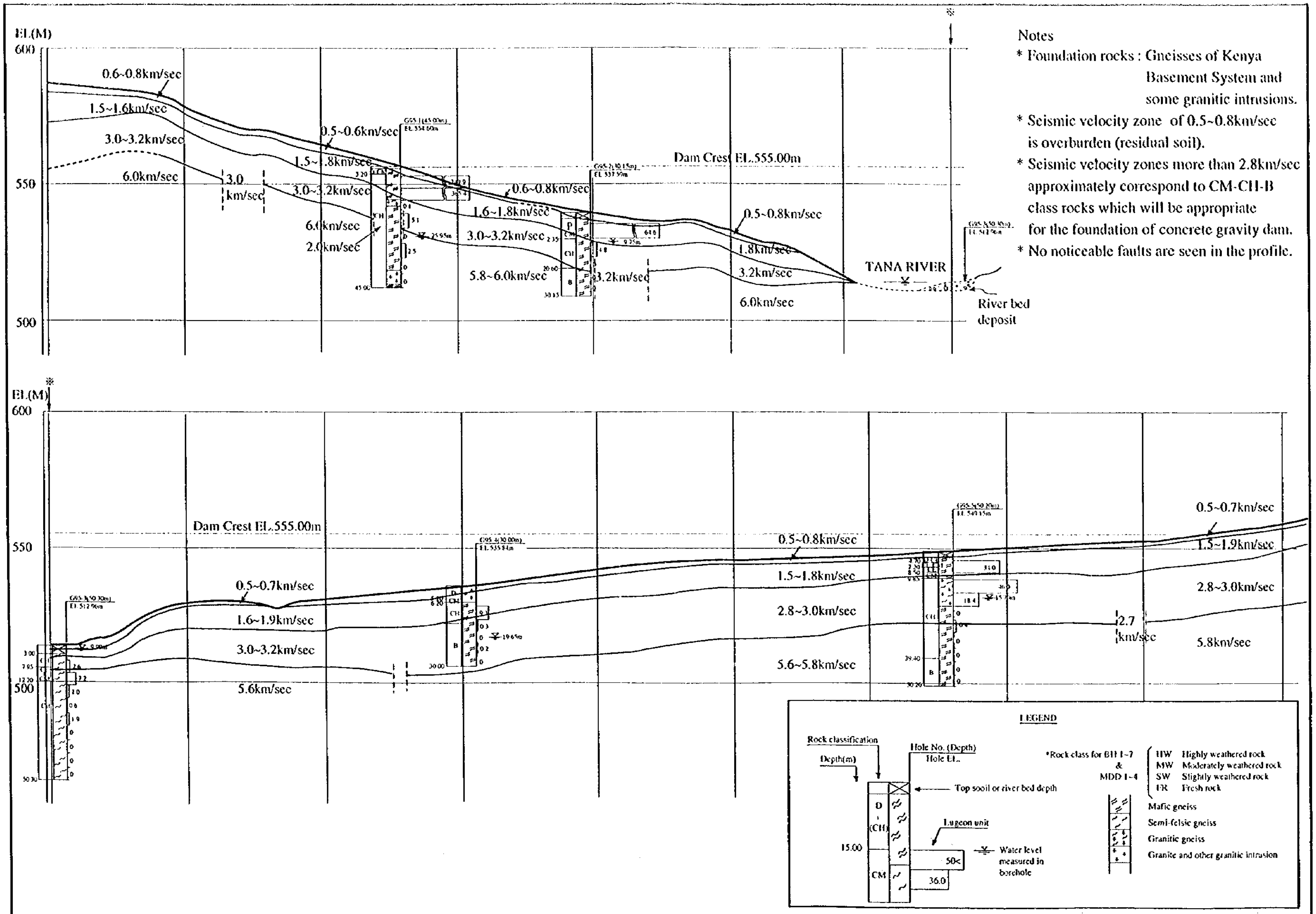
JAPAN INTERNATIONAL COOPERATION AGENCY	Geology of the Reservoir Area	Fig. No.
REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT		C1.2.1



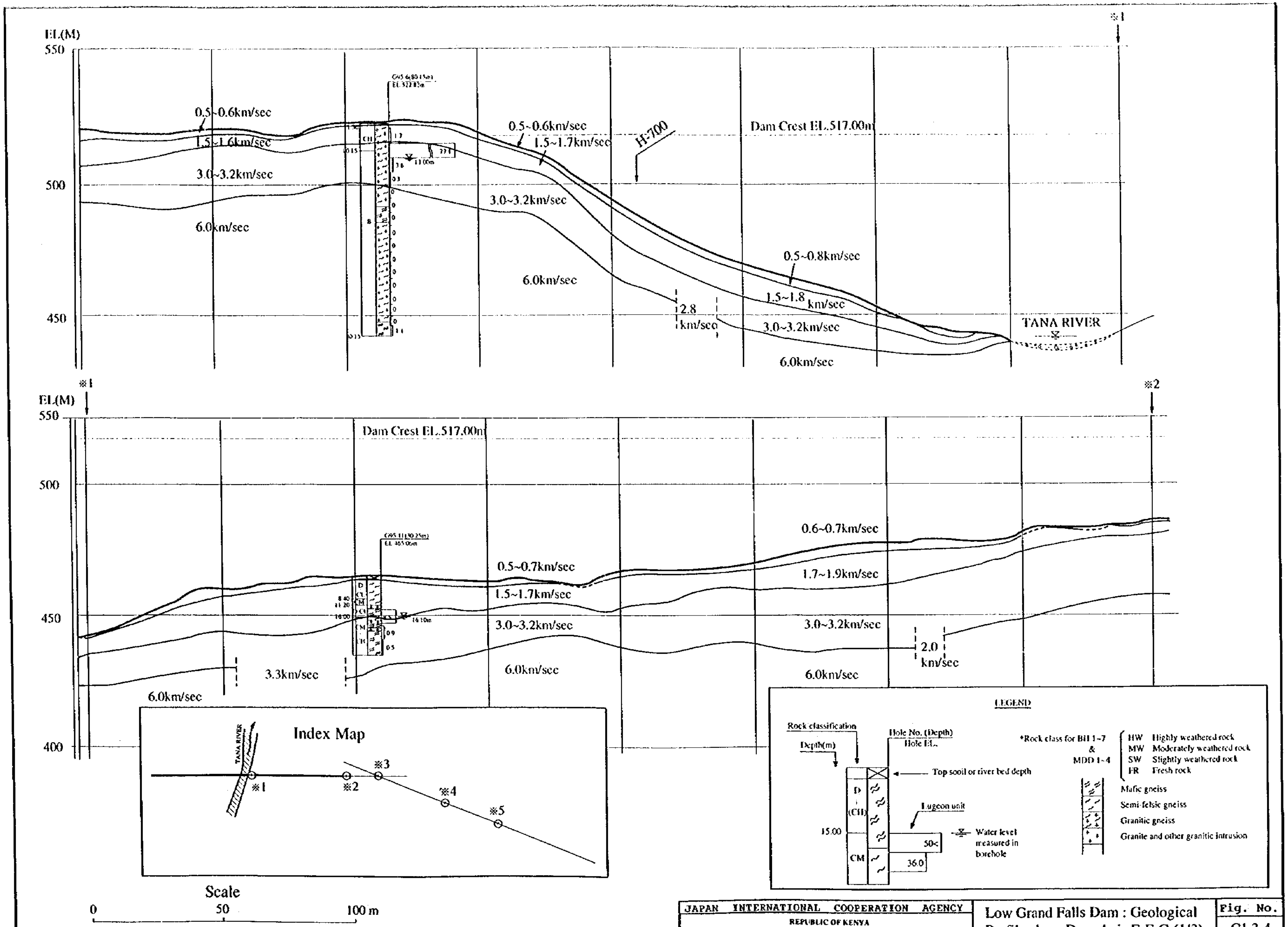
JAPAN INTERNATIONAL COOPERATION AGENCY	Investigation Location and Geological Map for Mutonga Project	Fig. No.
REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT		C1.3.1



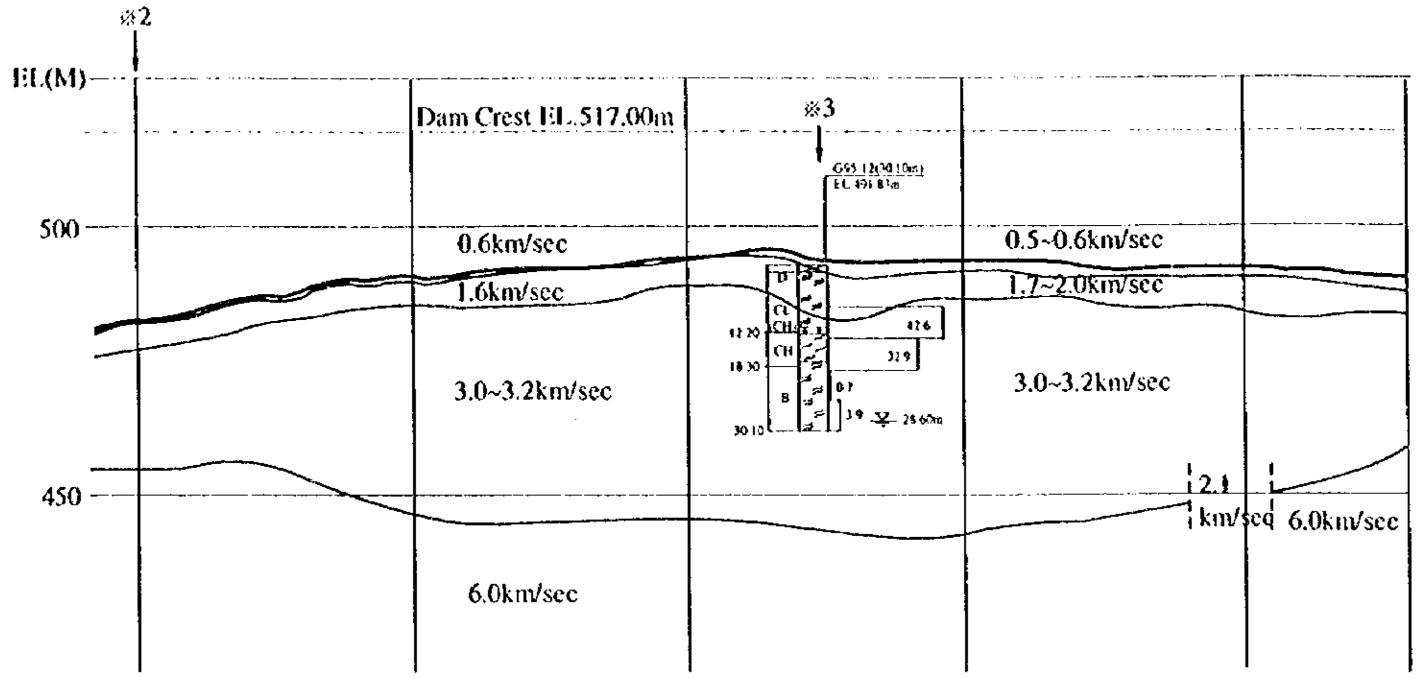
JAPAN INTERNATIONAL COOPERATION AGENCY REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT	Investigation Location and Geological Map for Low Grand Falls Project	Fig. No. C1.3.2



JAPAN INTERNATIONAL COOPERATION AGENCY REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT	MUTONGA DAM : Geological Profile along Dam Axis	Fig. No. C1.3.3

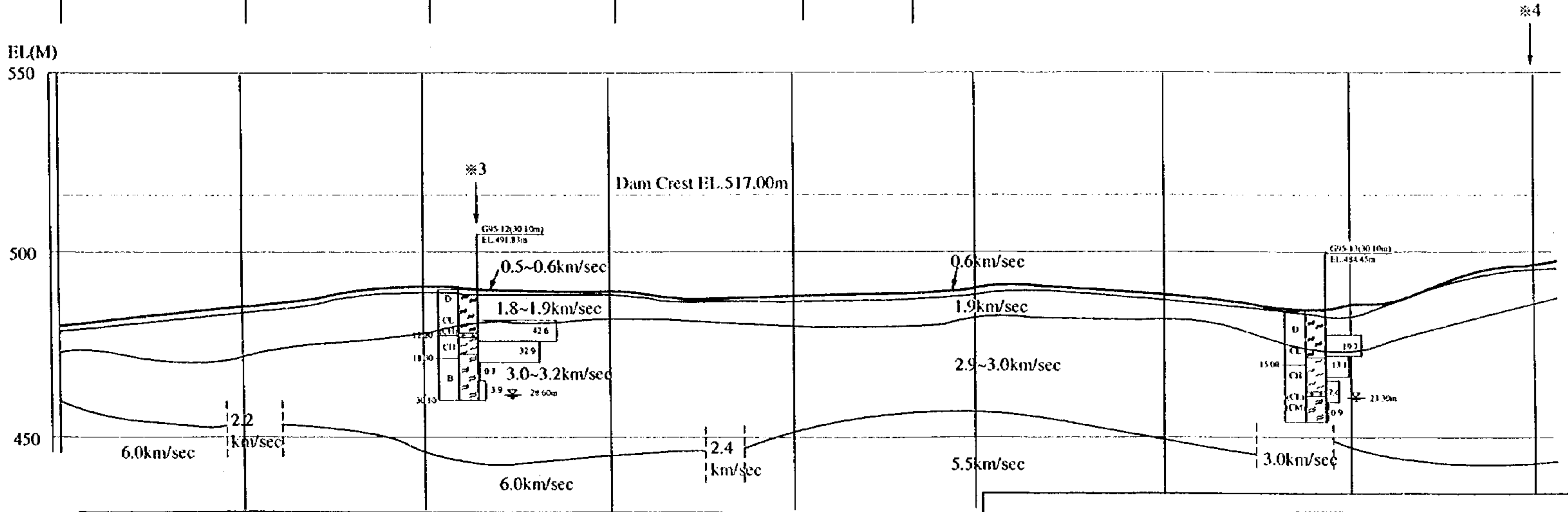


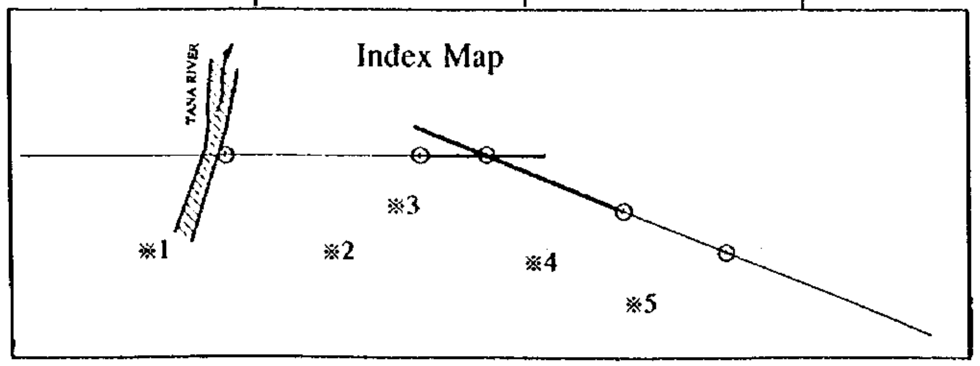
JAPAN INTERNATIONAL COOPERATION AGENCY REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT	Low Grand Falls Dam : Geological Profile along Dam Axis E-F-G (1/3)	Fig. No. C1.3.4

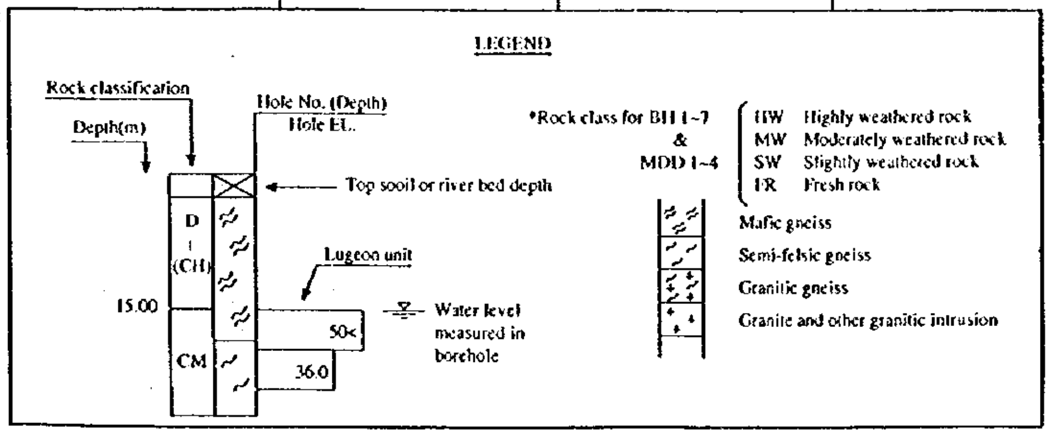


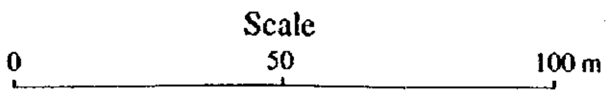
Notes for Dam axis E-F-G

* Foundation rocks : Gneisses of Kenyan Basement System and some granitic intrusions.
* Seismic velocity zone of 0.5~0.8km/sec is overburden (residual soil).
* Seismic velocity zones more than 2.8km/sec approximately correspond to CM-CH-B class rocks which will be appropriate for the foundation of core zone (rock fill section), and for the foundation of concrete gravity dam.
* No noticeable faults are seen in the profile along dam axis E-F-G.

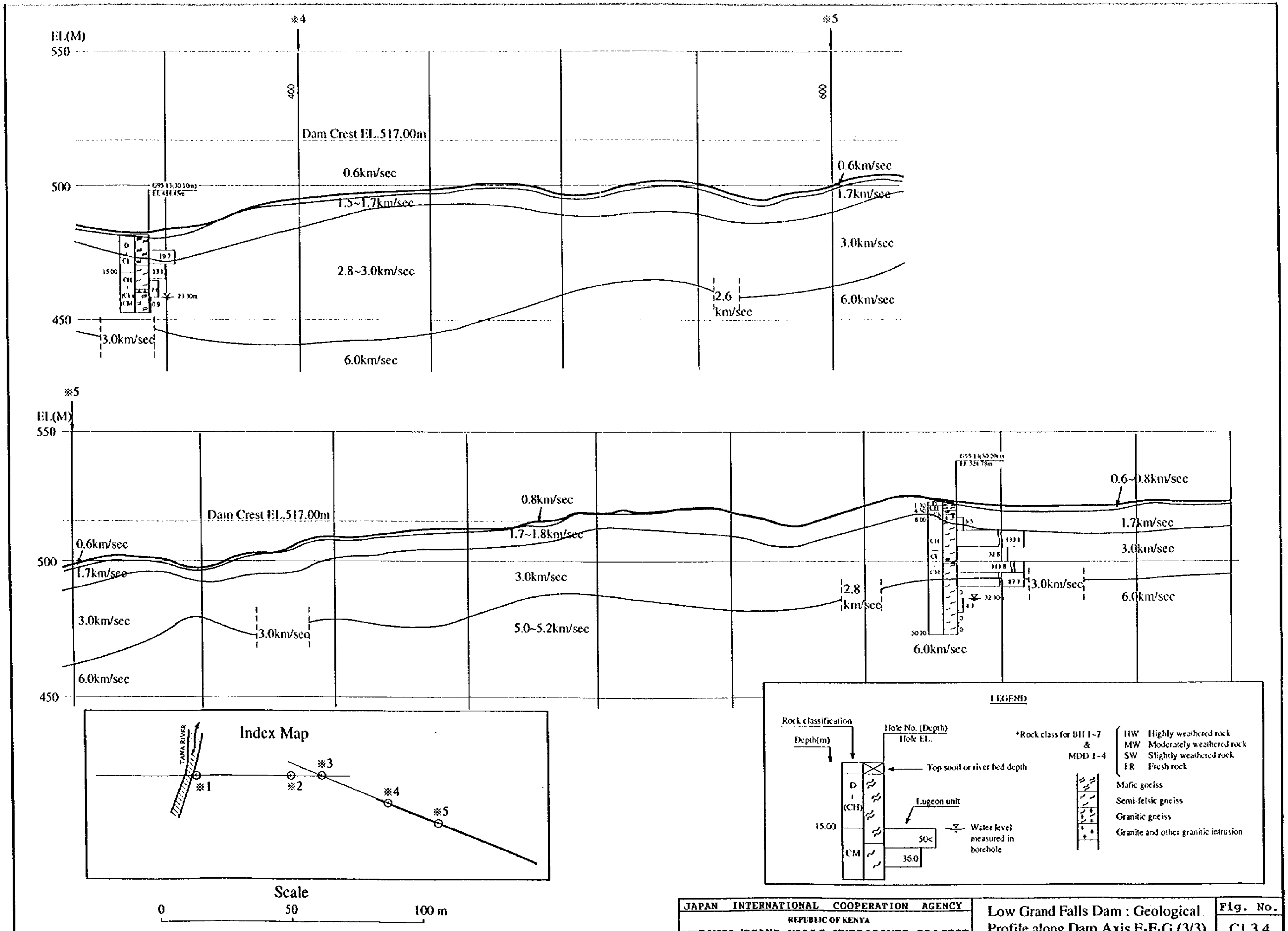




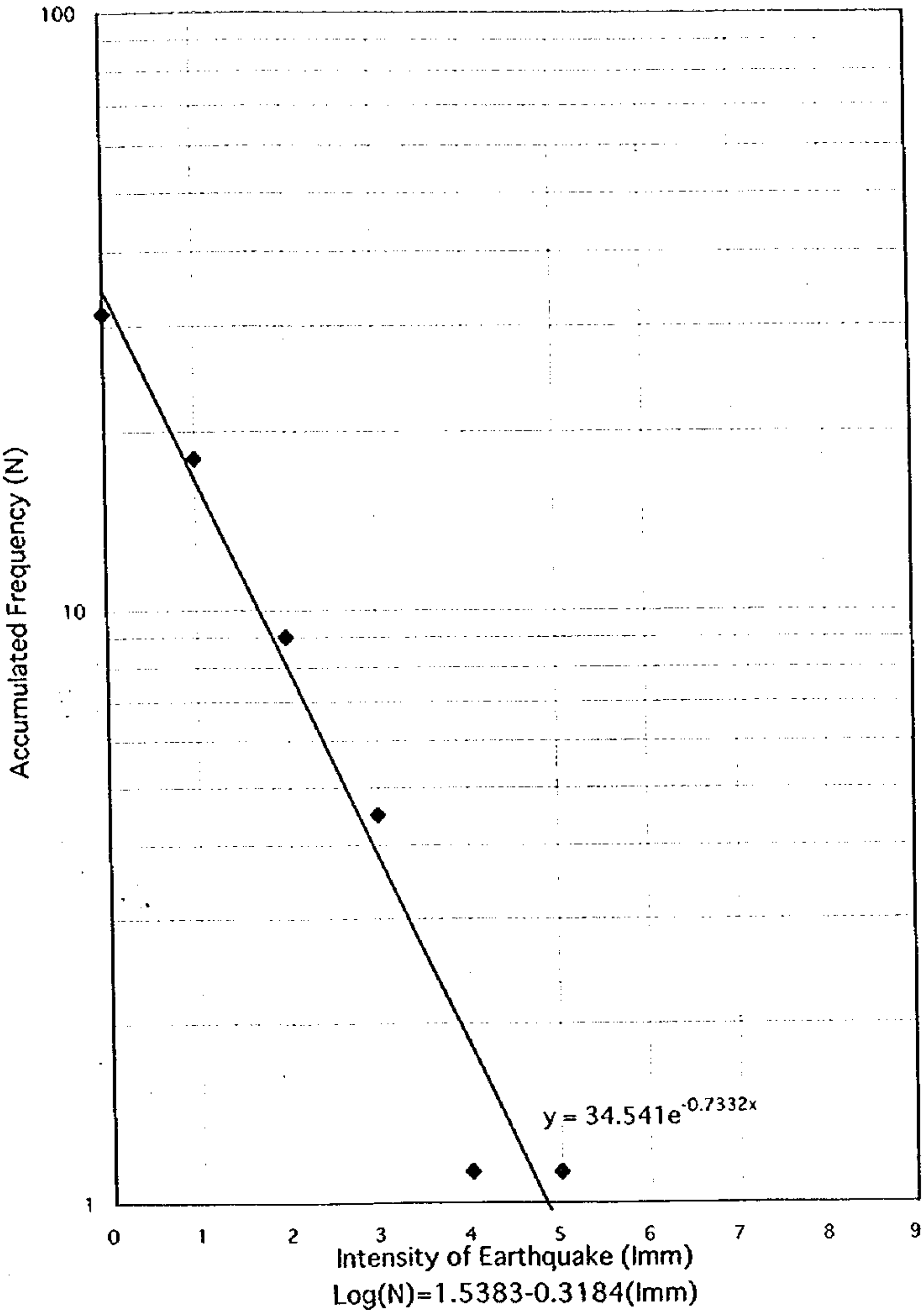




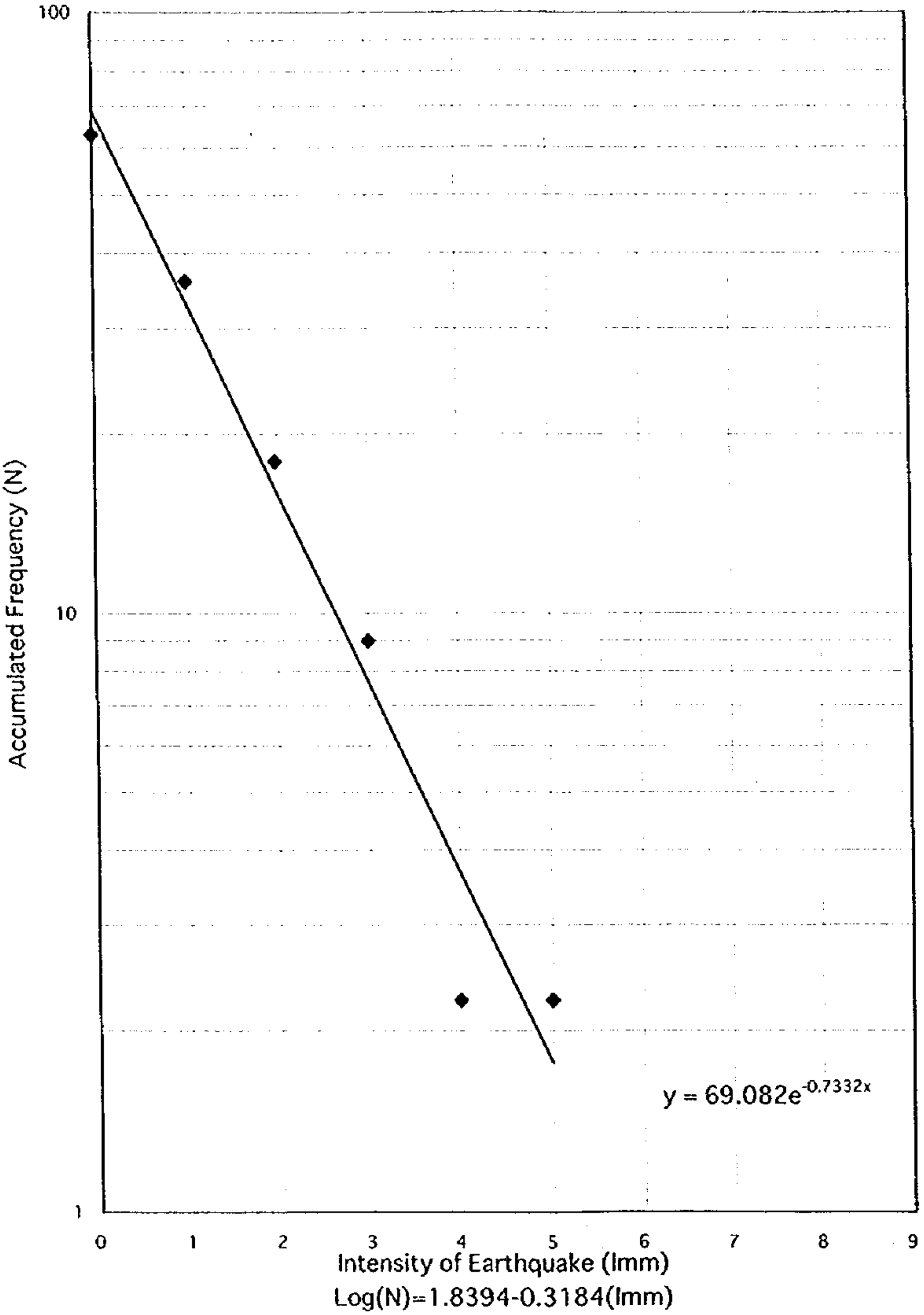
JAPAN INTERNATIONAL COOPERATION AGENCY REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT	Low Grand Falls Dam : Geological Profile along Dam Axis E-F-G (2/3)	Fig. No. C1.3.4



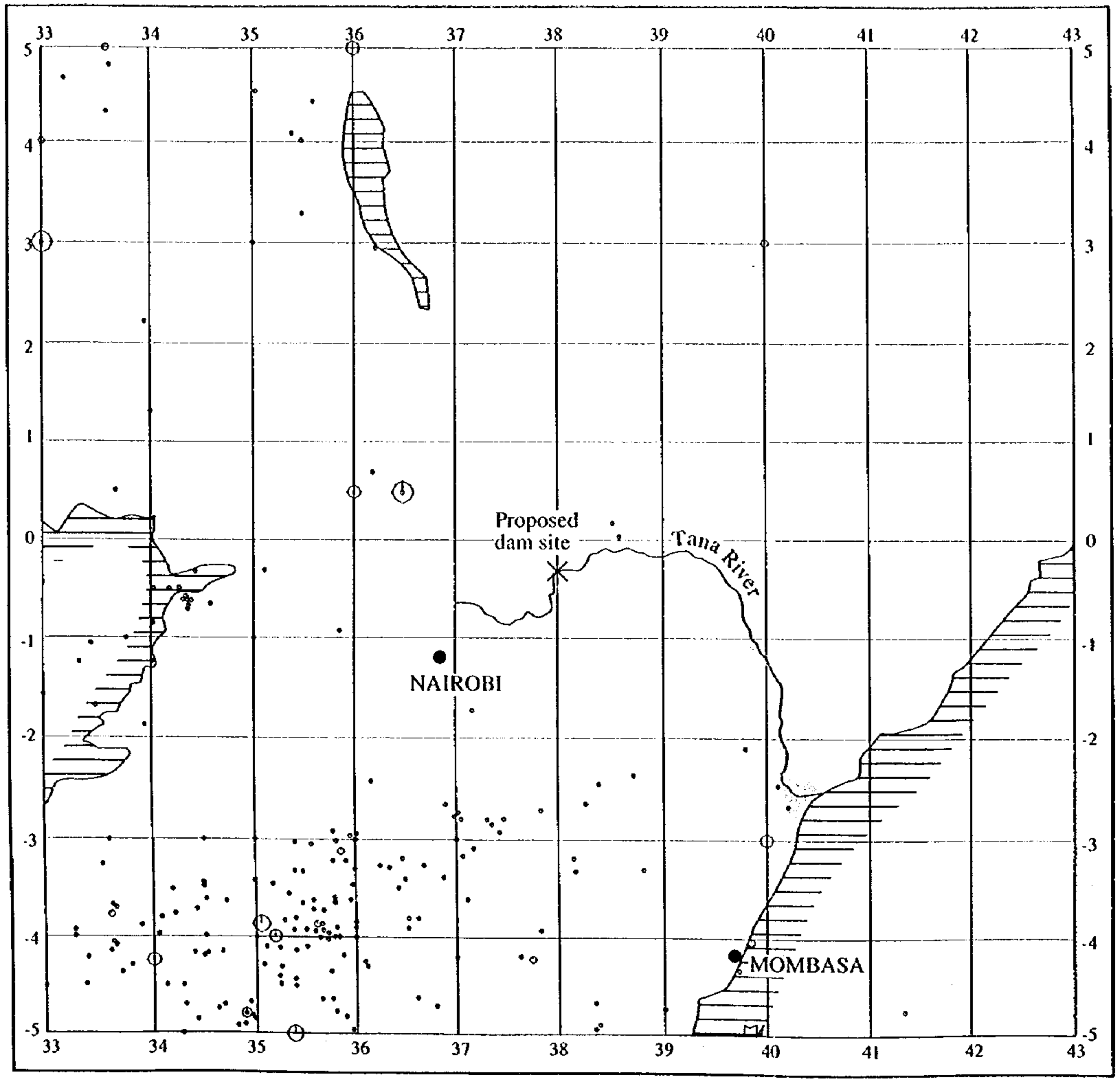
JAPAN INTERNATIONAL COOPERATION AGENCY	Low Grand Falls Dam : Geological Profile along Dam Axis E-F-G (3/3)	Fig. No.
REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT		C1.3.4



JAPAN INTERNATIONAL COOPERATION AGENCY	Relation between Accumulated Frequency and Intensity of Earthquakes, Cornell's Method; for 100 years	Fig. No.
REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT		C1.4.1



JAPAN INTERNATIONAL COOPERATION AGENCY	Relation between Accumulated Frequency and Intensity of Earthquakes, Cornell's Method; for 200 years	Fig. No.
REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT		C1.4.2



Source: British Geological Survey

KEY TO SYMBOLS

DEPTHS (kms)

⦶		<	60
[!]	60	=< AND <	300
△	300	=<	

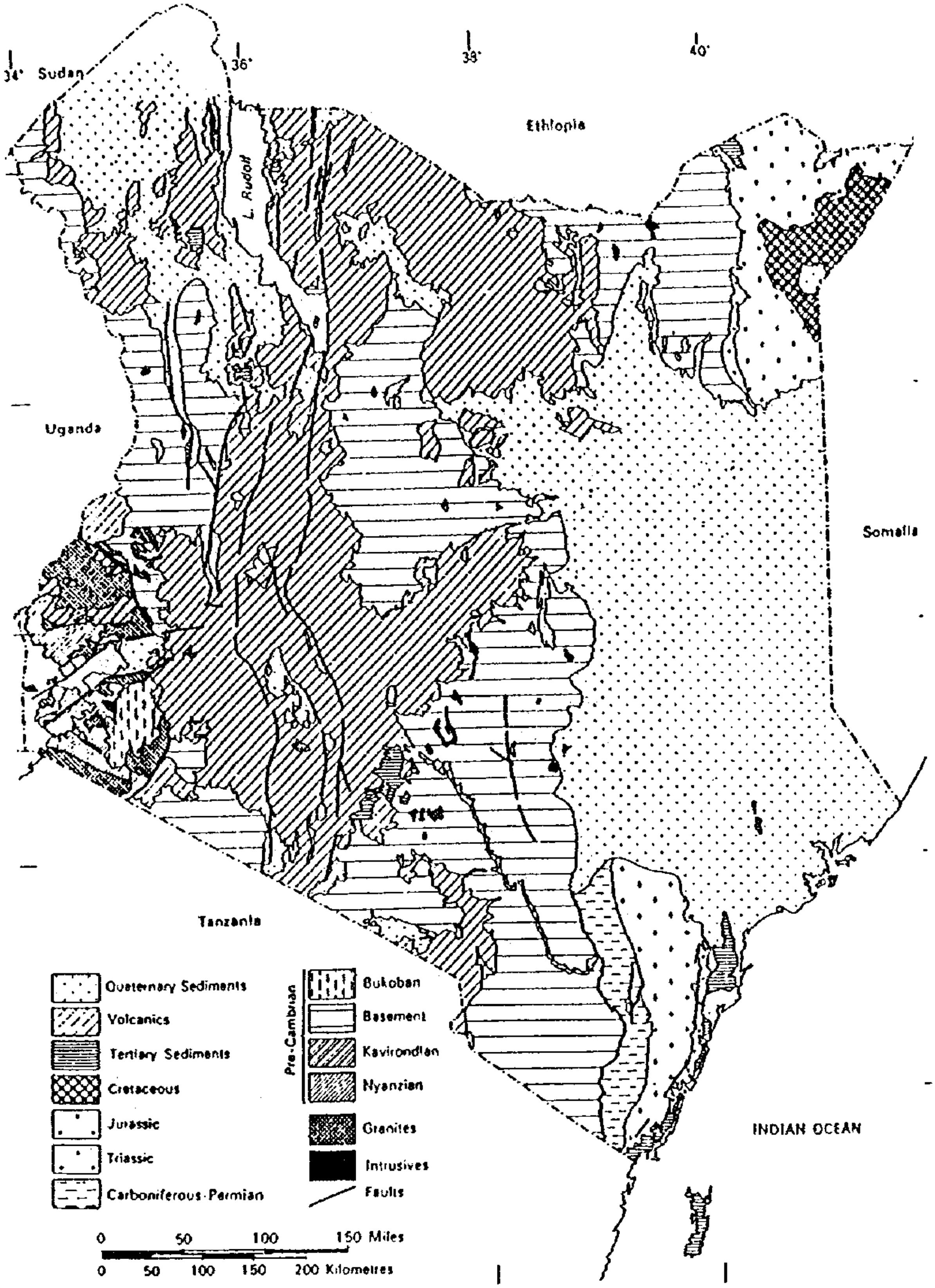
MAGNITUDE
(Symbol Radius)

	<	5.0
5.0	=< AND <	5.5
5.5	=< AND<	6.0
6.0	=< AND<	6.5
6.5	=< AND <	7.0
7.0	=< AND <	7.5
7.5	=< AND <	8.0
8.0	=< AND <	8.5
8.5	=<	

SITE

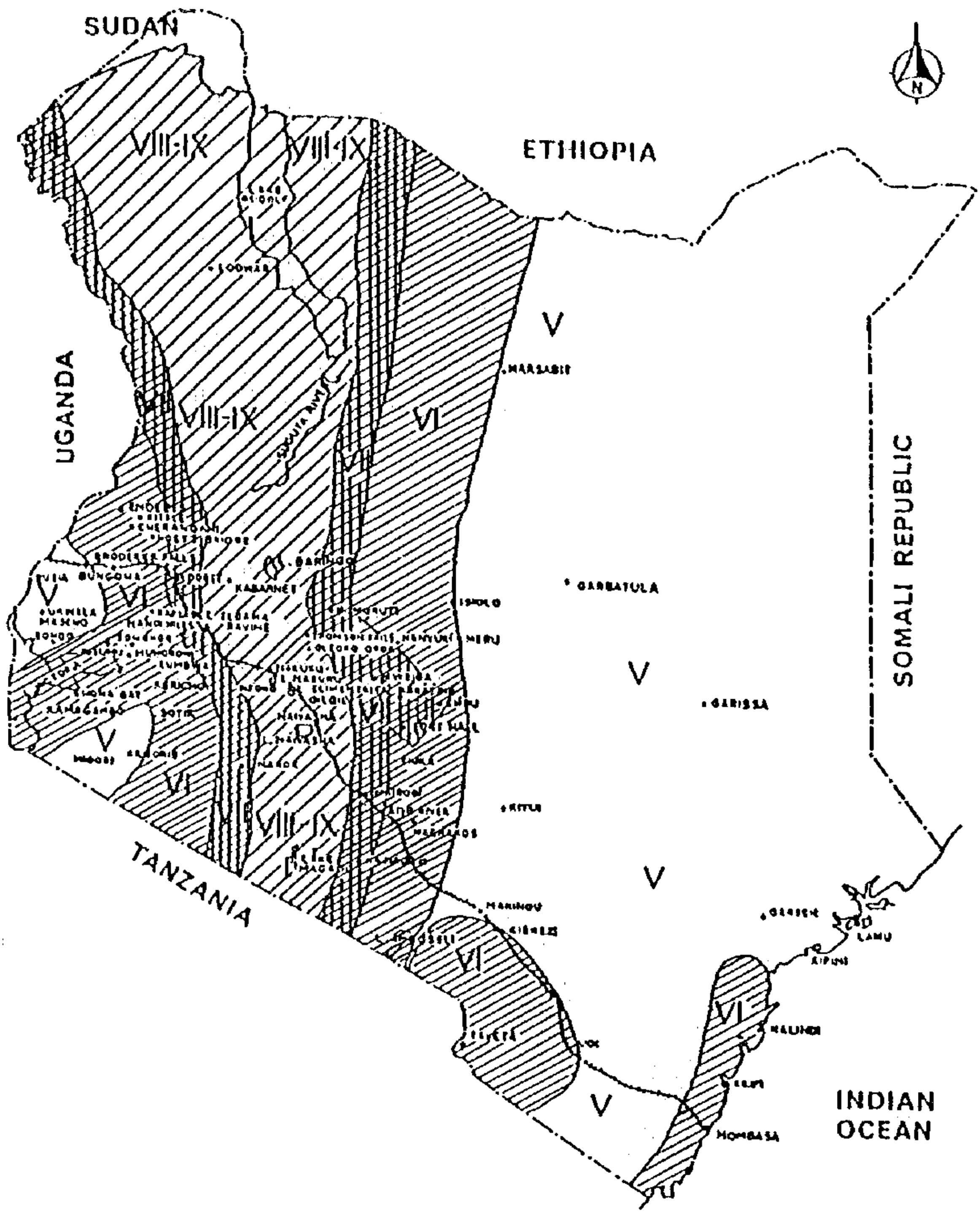
X Position of Site

JAPAN INTERNATIONAL COOPERATION AGENCY REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT	Distribution of Earthquakes; Epicenters around Project Site	Fig. No. C1.4.3

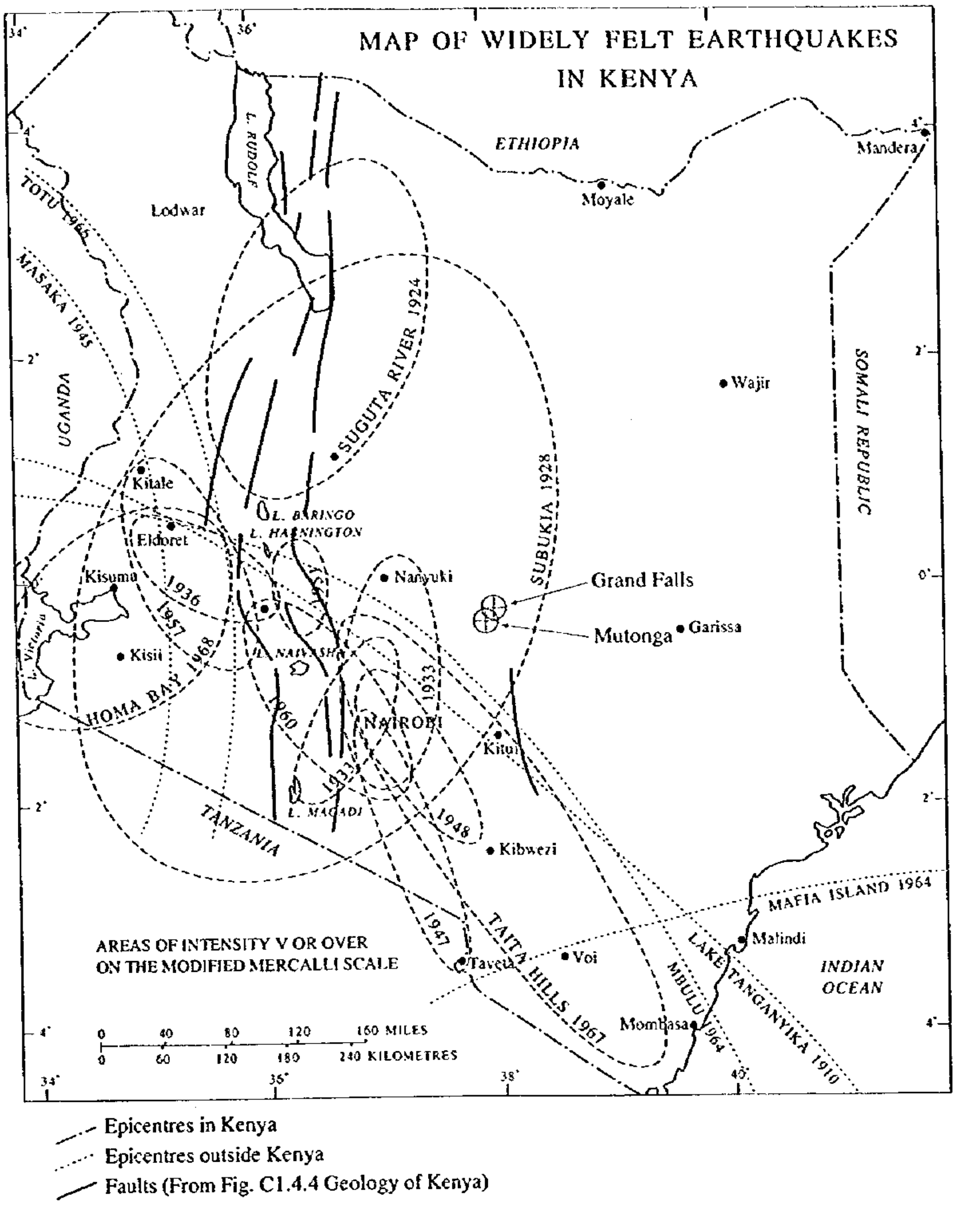


Source: Mines and Geological Department(1967)

JAPAN INTERNATIONAL COOPERATION AGENCY	Geology of Kenya	Fig. No.
REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT		C1.4.4



JAPAN INTERNATIONAL COOPERATION AGENCY	Seismic Zoning Map of Kenya	Fig. No.
REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT		C1.4.5



JAPAN INTERNATIONAL COOPERATION AGENCY	Widely Felt Earthquakes in Kenya	Fig. No.
REPUBLIC OF KENYA MUTONGA/GRAND FALLS HYDROPOWER PROJECT		C1.4.6