is very gentle at approximately 1/500, and the Kihansi, while meandering, changes its course to the northeast.

7.3.2 Geologies of Upper Kihansi and Lower Kihansi Project Area

(1) Rock Types

The Upper Kihansi and Lower Kihansi project sites, as shown in Figs. 7-4 and 7-5, are composed of gneisses, and slope wash and alluvium which cover these gneisses at parts.

The "gneisses" mentioned here is a general term for biotite gneiss, quartz gneiss, amphibolite, and lamprophyre, and of these, biotite gneiss is distributed the most widely. According to existing literature, quartzo-feldspathic gneiss is predominant in this area, but at least in the surrounding areas of the planned structures, since biotite is found in comparatively large quantity in the rocks, these rocks will hereafter be called biotite gneiss in this Report.

Slope wash and alluvium are mainly distributed downstream of the Lower Kihansi dam site, and are seen at the foots of cliffs and in the Kilombero Valley.

(2) Geological Structure and Faults

The foliation of the gneisses trends as a whole in the NNE-SSW direction, and dips 20° to 70° to the west. According to aerial photo interpretation of this area there are predominant lineament patterns in the N-S, NE-SW, and WNW-ESE directions. Particularly, many of the lineament patterns in the N-S and WNW-ESE directions among these are long and continuous. Faults confirmed by outcropping at the surface are only the two in the vicinity of the Upper Kihansi dam site, and even at Uzungwa Scarp considered to be a fault escarpment, there are no sites where faults have been confirmed at the surface.

(3) Weathering

Although not shown in Figs. 7-4 and 7-5, a comparatively thick weathered layer covers the area upstream from the vicinity of the Lower Kihansi dam site. According to boring investigations made at the Upper Kihansi dam site, there are places where a weathered layer 30 m or more in thickness has been confirmed. Since outcrops of bedrock are seen comparatively frequently at the river bed of this area as a whole, it may be said there is a trend for the weathered layer to be thick at the gently-sloped ridges and thin in the vicinity of the river bed.

(4) Landslides and Scars

According to aerial photo interpretation and surface reconnaissances, topography indicating occurrence of landsliding cannot be seen in this area. All of the scars are of small scale, where soil or weathered material at the surface have slidden down.

(5) Rock Evaluation

In classifying rock as the foundation of a structure, "weathering", "hardness" and "interval of cracks" of the rock may be considered as fundamental factors governing engineering geological properties. In view of this, the cores obtained in the boring investigations of this area have been classified according to the standard of rock classification given in Table 7-3. Rock classification, in the first place, is to be done on side walls of adits and excavated surfaces of rock for classification according to five grades focusing on the abovementioned three fundamental factors to comprehensively evaluate the engineering geological properties of rock as foundations of structures based on these classifications.

However, since adit excavation and rock excavation have not been carried out in this investigation, the rock evaluation criteria given in Table 7-4 were tentatively prepared with boring core observation results as the means for evaluating rock from the standpoint of engineering geology. The rock evaluations (grades) based on the above are used in the explanations of the geological properties of the various sites described below.

The rock evaluations and the results of tests concerning rock strengths of boring cores obtained at the various sites are given in Table 7-5. Organizing the test results by rock type and by rock evaluation, they are as shown below, and it can be seen that the rock evaluations used here reflect the engineering geological properties to an extent.

Rock Type	Rock Evaluation	Unconfined Compressive Strength (kgf/cm^2) Av. values in ( )	Tensile Strength (kgf/cm^2) Av. values in ( )
Biotite gneiss	ⓑ	559 (559)	-
"	ⓒ	80 - 543 (243)	10 - 32 (19)
"	ⓓ	108 (108)	22 (22)
Quartz gneiss	ⓑ	784 - 1109 (947)	40 - 68 (54)
"	ⓒ	701 - 799 (750)	-
Amphibolite	ⓑ	1844 (1844)	152 (152)
"	ⓒ	571 (571)	25 (25)
Lamprophyre	ⓒ	2335 (2335)	105 (105)

The rock evaluation criteria given in Table 7-4 are of a nature that they should be modified if there are any points to be changed on comparisons with boring cores obtained when investigations are made in the future through measures such as adit excavation.

Table 7-3 Standard of Rock Classification for Drilled Core

Weathering		Hardness		Interval of Cracks	
1	Very Fresh. No weathering of mineral component.	1	Very hard. Broken into knifeedged pieces by strong hammer blow.	1	Over 30 cm
2	Fresh. Some minerals are weathered slightly. Usually no brown crack.	2	Hard. Broken into pieces by strong hammer blow.	2	10 - 30 cm
3	Fairly fresh. Some minerals are weathered. Cracks are stained and with weathered mineral.	3	Brittle. Broken into pieces by medium hammer blow.	3	3 - 10 cm
4	Weathered. Fresh portions still remain partially.	4	Very brittle. Easy broken into pieces by medium hammber blow.	4	1 - 3 cm
5	Strongly weathered. Most minerals are weathered and altered to second minerals.	5	Soft. Able to dig with hammer.	5	Under 1 cm

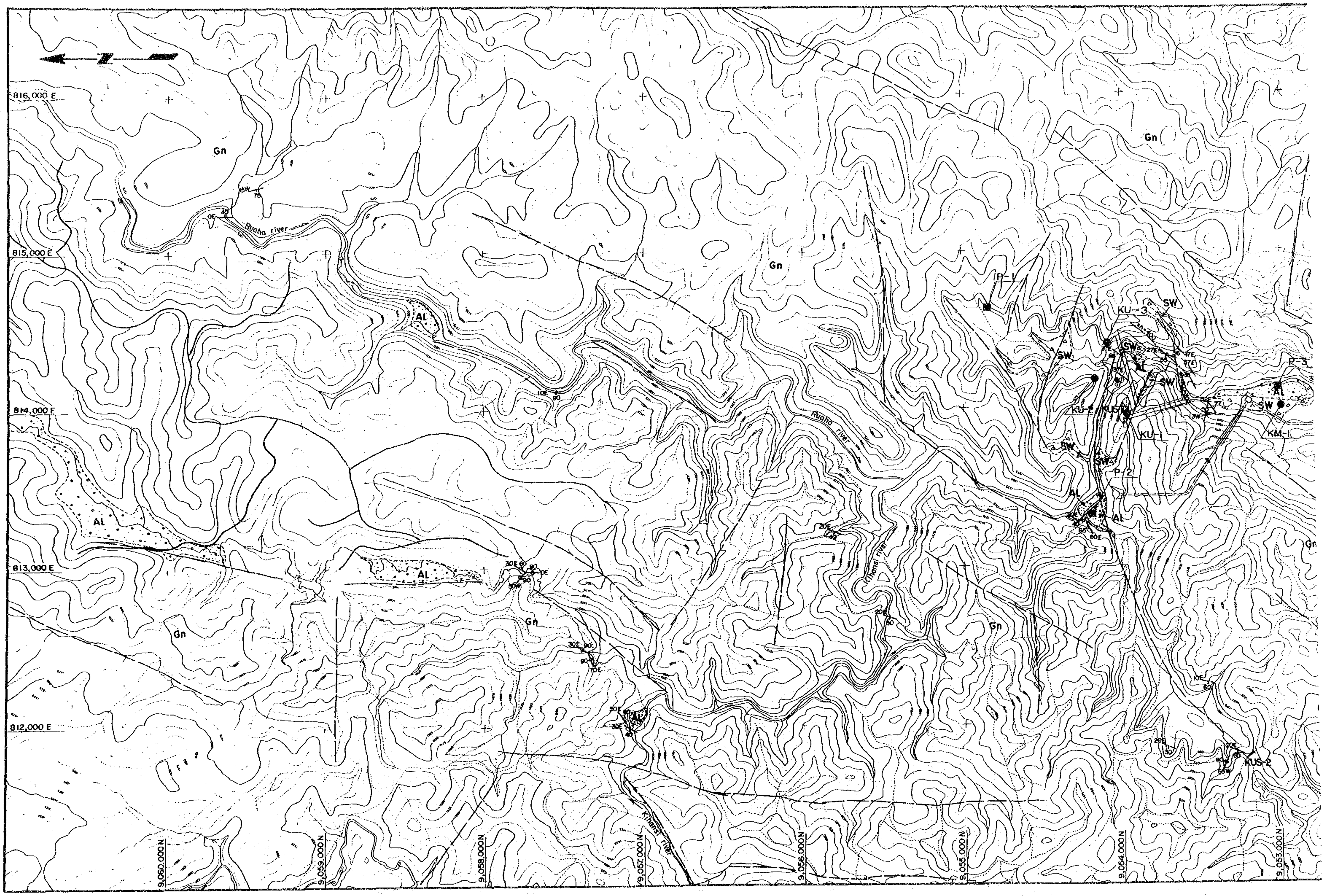
Table 7-4 Rock Evaluation

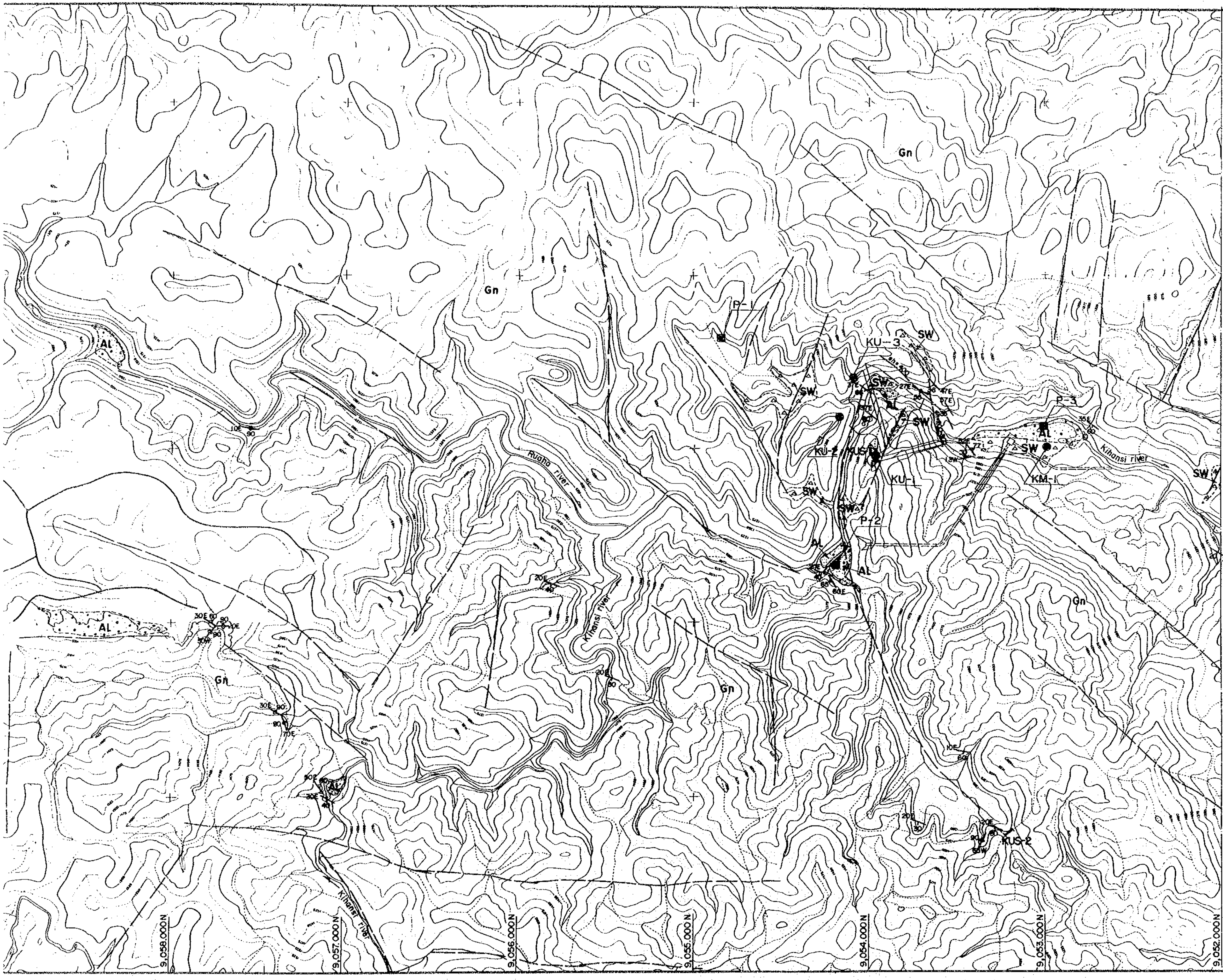
Grade	Field recognition	Standard of rock classification (Core) : Main rank Weathering	Hardness	Interval of cracks	Master plan report classification (Nov. 1984)
ⓐ	Very Fresh. No weathering of mineral component. Very hard.	①~ 2	①~ 2	①~ 2	F/I
ⓑ	Fresh. Some minerals are weathered slightly. Hard.	1 ~②~ 3	1 ~②~ 3	1 ~②~ 3	SW/II
ⓒ	Fairly fresh. Some minerals are weathered. Cracks are stained and with weathered mineral. Brittle.	2 ~③~ 4	2 ~③~ 4	2 ~③~ 4	MW/III
ⓓ	Weathered. Fresh portions still remain partially. Very brittle. Contained fractured zone.	3 ~④~ 5	3 ~④~ 5	3 ~④~ 5	HW/IV
ⓔ	Strongly weathered. Most minerals are weathered and altered to second minerals. Soft. Contained fault clay zone.	4 ~⑤	4 ~⑤	4 ~⑤	CW/V
Residual soil ⓔ	No recognisable rock texture. Surface layer contains humus and plant roots.	-	-	-	RS/VI

Table 7-5 Results of Drilled Core Test

Hole No. in Depth (m)	Rock Name	Rock Evaluation	Specific Gravity	Absorption (%)	Unconfined Compression (kgf/cm^2)	Tensile Splitting (kgf/cm^2)
KU-1 33.2-33.5	B-Gn	c - (d)	2.1	2.8	110	10
" 35.4-35.6	Q-Gn	c	2.3	0.4	701	-
" 35.7-35.9	"	c	2.2	0.6	799	-
KU-3 30.5-30.8	Am	c - (d)	2.4	0.6	571	25
" 36.7-37.0	Q-Gn	b	2.1	0.6	784	40
KL-1 5.5-5.8	B-Gn	c - (d)	2.2	3.9	80	-
" 15.0-15.3	"	c - (b)	2.3	1.2	154	17
" 17.5-18.0	La	c - (b)	2.9	0.03	2,335	105
KL-2 9.7-10.0	B-Gn	c - (b)	2.1	2.6	138	15
" 15.5-16.0	Am	b - (a)	2.9	0.03	1,844	152
KL-5 6.8-7.0	B-Gn	c - (b)	2.3	0.6	424	32
" 7.5-7.8	"	c - (b)	2.3	0.5	543	23
" 11.5-11.8	"	d - (c)	3.0	1.3	108	22
" 18.5-19.0	"	b - (c)	2.3	0.5	559	-
KM-1 18.3-18.7	Q-Gn	b	2.3	0.3	1,109	68
KM-2 17.2-17.4	B-Gn	c	2.5	0.3	252	-
Site Q-2 Rock	-	-	2.4	0.3	807	31

Note: "B-Gn" Biotite Gneiss
"Q-Gn" Quartz Gneiss
"Am" Amphibolite
"La" Lamprophyre

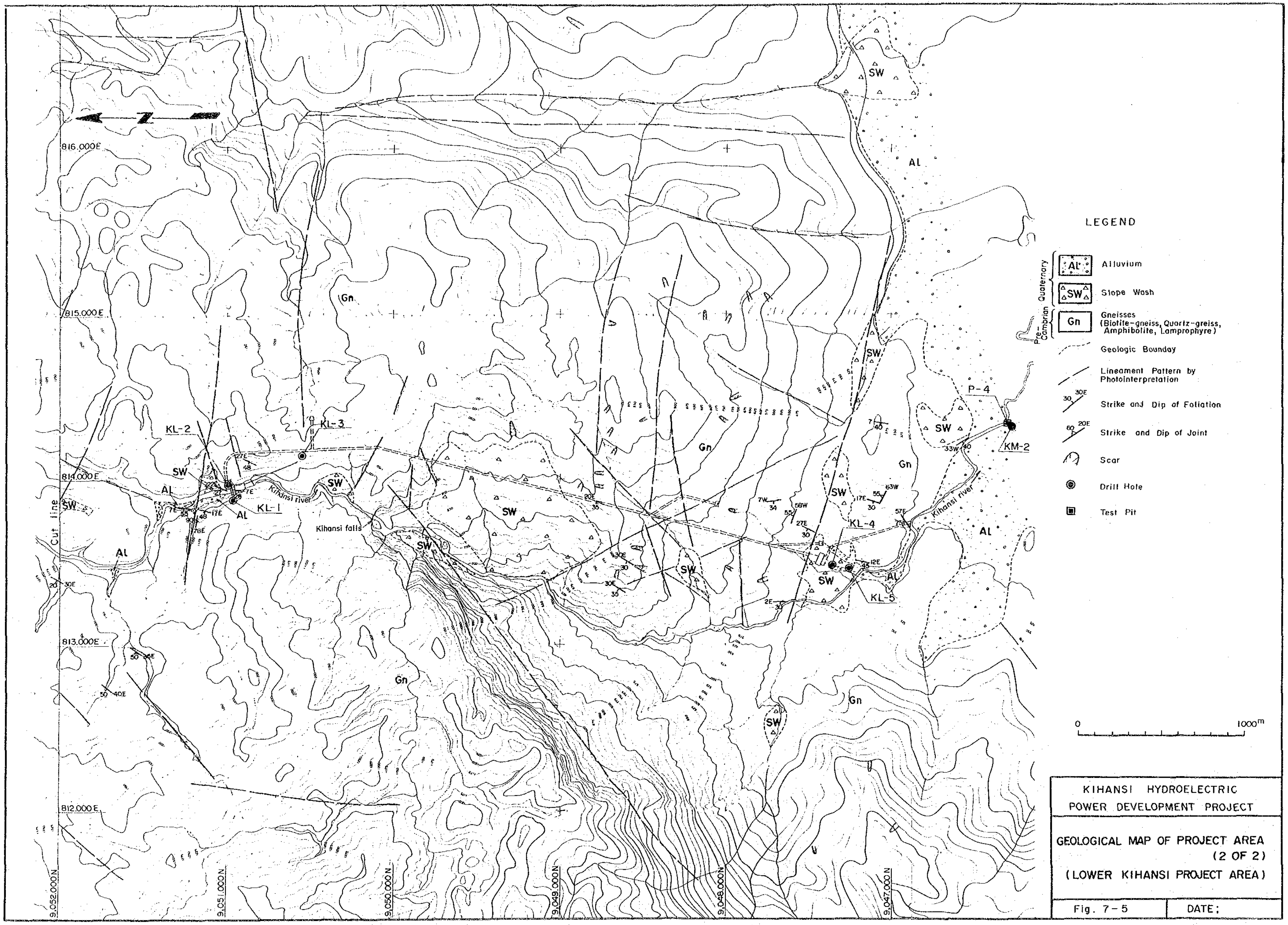

N
816,000 E
815,000 E
814,000 E
813,000 E
812,000 E
Gn
AL
Ruaha river
Kihansi river
P-1
P-2
P-3
KU-1
KU-2
KU-3
KUS-1
KUS-2
KM-1
SW
9,060,000 N
9,059,000 N
9,058,000 N
9,057,000 N
9,056,000 N
9,055,000 N
9,054,000 N
9,053,000 N



KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL MAP OF PROJECT AREA (1 OF 2) (UPPER KIHANSI PROJECT AREA)

Fig. 7-4 | DATE;



KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL MAP OF PROJECT AREA (2 OF 2) (LOWER KIHANSI PROJECT AREA)

Fig. 7-5 | DATE:

7.4 Geology of Upper Kihansi Project Site

7.4.1 Reservoir

(1) Topography

Upper Kihansi Reservoir of design high water level at EL. 1,360 m is surrounded by comparatively gentle mountains of elevation from 1,400 m to 1,500 m. The distance from the dam site to the end of the reservoir backwater is approximately 8 km, and the high water level valley width at the maximum point is approximately 400 m.

There are the two large rivers of the Kihansi and the Ruaha in the projected reservoir area, and the two merge approximately 2 km upstream of the projected dam site. The average river-bed gradients inside the projected reservoir area are approximately 1/65 for the former and approximately 1/130 for the latter, and both of the rivers run down with small waterfalls here and there. Comparatively large tributaries which join the mainstream in the vicinity of the dam site are the one at the left bank immediately upstream of the dam site, another at the left bank approximately 1.8 km upstream, and one at the right bank approximately 1.0 km upstream.

(2) Geology

The reservoir area consists of gneisses, in which foliation can be seen in the N 0° - 37°E, 30° - 60°NW direction roughly parallel to the flow of the Ruaha River, and slope wash and alluvium. Comparatively fresh gneisses may be observed at the river bed where small waterfalls are formed, but at the gently sloped mountainside outcrops of rock are extremely few since residual soil lies on the surface over a wide area. Slope wash and alluvium are only found locally at parts of the Kihansi River, Ruaha River, and their tributaries, all of which consist mainly of fine sand.

According to aerial photo interpretation, lineament patterns of NE-SW and WNW-ESE systems are predominant in the reservoir area. The NE-SW lineament pattern more or less coincides with the direction of foliation of gneisses in the basement rock. The WNW-ESE lineament pattern crosses roughly orthogonal to the former, and there is a possibility of existence of continuous joints or faults.

- Geological Properties in surroundings of Reservoir

The point approximately 2.5 km west-southwest of the dam site, as shown in Fig. 7-6, comprises a thin saddle. The results of seismic prospecting performed there with the purpose of investigating the geological properties are also shown in Fig. 7-6.

On comparison of the results of seismic prospecting done at KU-1 drillhole at the dam site, it is estimated that this thin saddle is covered by residual soil or weathered rock of thickness about 15 m and rock evaluation of Grade ⓔ.

(3) Engineering Geological Evaluations

Evaluations of the Upper Kihansi reservoir area from the viewpoint of engineering geology may be summarized as follows:

i) Slope Stability

The slopes of the reservoir and in the surroundings are gentle and are widely covered by residual soil. Landslide topography and large-scale distribution of slope wash are not recognizable. It is judged that the stability of reservoir slopes will not be endangered under present conditions and by future storage of water.

ii) Watertightness

This area is mainly constituted of gneisses and their weathered products, and geologically-speaking, it is thought the watertightness of the area will be high. However, the thin saddle at the right-bank side of the reservoir approximately 2.5 km west-southwest of the dam site is adjacent to another river basin, and depending on the geological properties, it could be possible that water will escape outside. It is estimated from seismic prospecting that this saddle is covered with fairly thick residual soil or weathered rock, and it will be necessary for investigations of permeability to be made hereafter along with carrying out of accurate topographic surveying.

7.4.2 Dam

(1) Topography

The dam site is located approximately 2 km downstream from the confluence of the Kihansi River and the Ruaha River, where the Kihansi changes course to the south at a river-bed elevation of approximately 1,270 m. The dam site has inclinations of approximately 40 deg at both banks. Immediately downstream of the projected dam site on the right-bank side there is a gully in the WNW-ESE direction roughly parallel to the Kihansi River so that the right-bank side takes the form of a scraggy ridge sticking out. The river-bed width is 20 to 30 m, and the Kihansi River which flows down gently to this point starts dropping down in a continuation of waterfalls 5 to 10 m in height downstream of the projected dam axis.

Vegetation at the dam site is slightly dense with the site covered with grass and bushes.

(2) Geology

i) Rock Types

The dam site, as shown in Figs. 7-7 and 7-8, is composed of biotite gneiss and quartz gneiss, overlying with slope wash and alluvium.

The biotite gneiss and quartz gneiss, which comprise the basement rock are seen to be comparatively fresh and sound at the surface in the river bed of the Kihansi River. On the other hand, slope wash and alluvium are distributed in parts at foots of slopes and gullies or along the Kihansi River. The slope wash is fine-grained on the whole, while alluvium contains large gravels in the fine-grained material.

According to boring investigations at the left-bank slope, amphibolitic gneiss is also found as a basement rock.

ii) Geological Structure and Faults

The foliation of gneiss, although showing some amount of variation in strike and dip locally, indicates as a whole a direction of N37° - 47°E, 36 - 70°MW for a dip to the right-bank side of the projected dam. Joints are seen in the same direction as the foliation and in a direction perpendicular to this. Two faults were confirmed at the ground surface downstream of the dam axis and parallel to the direction of foliation. The widths of fracturing of the faults are from 200 to 400 cm. These faults do not extent in the direction of the projected dam structure foundation.

Meanwhile, according to aerial photo interpretation, lineament patterns in the WNW-ESE direction are seen along the Kihansi River and along a gully downstream of the projected dam axis. These have not been confirmed through outcrops, but it is possible they are faults.

iii) Weathering

According to boring investigations, weathered rocks evaluated as Grade ⓔ to Grade ⓓ have been confirmed at the right-bank slope boring site to a thickness of approximately 24 m, at the left-bank slope boring site to a thickness of approximately 16 m, and further, at the boring site at a ridge sandwiched by the Kihansi River and a gully immediately upstream of the dam axis to a thickness of more than 30 m. At the bed of the Kihansi River there is wide distribution of comparatively fresh and hard rock evaluated as Grade ⓒ or higher.

iv) Bedrock Strength

If the weathered bedrocks at the right- and left-bank slopes of the dam site are excepted, the dam site is generally constituted of bedrock of rock evaluation not lower than Grade ⓒ. The unconfined compressive strengths and tensile strengths of these bedrocks are as given below according to the results of boring core tests.

Rock Type	Rock Evaluation	Unconfined Compressive Strength (kgf/cm^2)	Tensile Strength (kgf/cm^2)
Biotite gneiss	ⓒ	111 - 571	10 - 25
Quartz gneiss	ⓒ	701 - 799	-
"	ⓑ	784	40

v) Groundwater Level and Permeability

According to boring investigations at the slopes of both banks the groundwater tables of the two banks are not very high and are thought to be of a degree of rise only slightly above the river-bed elevation.

The permeability of the bedrock may be summarized as follows from the results of permeability tests performed in boreholes.

Rock Evaluation	Permeability Coefficient (k: cm/s)	Lugeon Value	Remarks
Grade ⓔ (Residual soil)	3×10^{-2} - 6×10^{-4}	-	k: an approximate value obtained from water level drop velocities in holes
Grades ⓔ - ⓓ (Weathered rock)	2×10^{-2} - 5×10^{-5}	-	k: Ditto
Grade ⓒ and higher (Fresh rock)	5×10^{-3} - 6×10^{-7}	1.2	Packer test at 1 section only. Other k approximate values obtained from water level drop velocities in holes

(3) Engineering Geological Evaluations

The engineering geological evaluations of the Upper Kihansi dam site may be summarized as follows:

- The dam site cannot be said to be of favorable topography as the Kihansi River bends, while in addition, there is a continuation of waterfalls, but in order to secure the design high water level of EL. 1,360 m, the present site is thought to be optimum in view of topographical and geological constraints.

- It is considered that approximately 80 m downstream from the line connecting the boring sites on the slopes of the two banks will improve geological conditions with weathering thinner. Consequently, the dam axis should be selected at this line.

- The weathered rocks evaluated as Grade ⓔ to Grade ⓓ distributed at the slopes of both banks at the dam site have a thickness of approximately 16 m at the left-bank boring site and approximately 24 m at the right-bank boring site, and these will need to be excavated and removed as they are unsuitable for a dam foundation.

- Bedrock distributed at deep parts is estimated to generally be rock of Grade ⓒ or higher and it is estimated that the strength possessed is ample for foundation rock of a dam of height approximately 100 m. However, as is clear from boring investigations, since deteriorated rock can be observed at parts even at a depth, it is considered that further detailed investigation by boring reaching deep inside and exploratory adits need to be done.

- The permeability of the dam foundation rock is seen to be fairly scattered at places. It is considered that further detailed investigations with improved accuracies will be needed.

- It will also be necessary for detailed investigations for evaluation of the possibility of faults and properties underground to be made regarding the two lineament patterns in the WNW-ESE direction recognized at the dam site.

7.4.3 Waterway Route and Powerhouse

(1) Topography

The waterway running north-south at approximately 900 m on the right-bank side of the Upper Kihansi dam site and the powerhouse located downstream consists of a comparatively steeply-sloped part of

EL. 1,410 m to 1,150 m, and a flat area of around EL. 1,150 m. Except at steep cliffs, vegetation consisting of grass and bushes similarly to the dam site covers the route.

(2) Geology

The waterway route and the powerhouse site, as shown in Fig. 7-9, is constituted of gneiss and overlying slope wash and alluvium. Gneiss, which is the basement rock, is seen to be comparatively fresh at steep cliffs behind the powerhouse, but at other areas it is covered by weathered layers and there are no places where bedrock outcrops can be confirmed. Slope wash and alluvium are distributed thinly at the powerhouse site, and mainly consist of fine-grained material and gravels.

The directions of foliation and joints are thought to be the same as at the Upper Kihansi dam site. There are no faults confirmed to exist in this area.

(3) Engineering Geological Evaluations

The engineering geological evaluations of the waterway route and the powerhouse site may be summarized as follows:

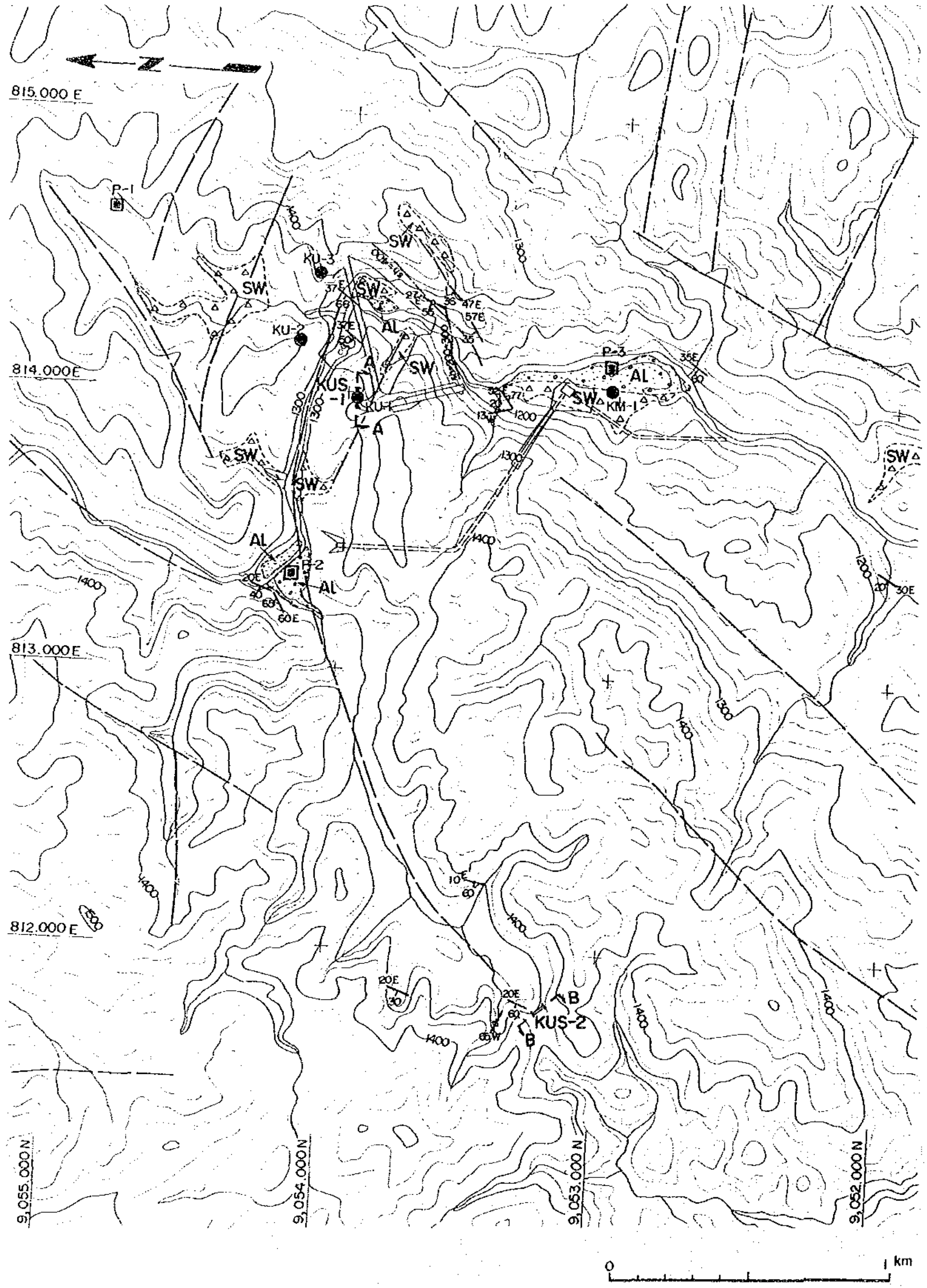
- Of the waterway route, the ground surface of the section including the projected intake and the headrace tunnel is expected to have a distribution of a slightly thick weathered layer. However, if the tunnel elevation is as projected, the tunnel will pass through comparatively fresh bedrock.

- Comparatively fresh rock is exposed at the slope of approximately 35 deg back of the powerhouse, and it is considered there will be no problem about stability of the slope.

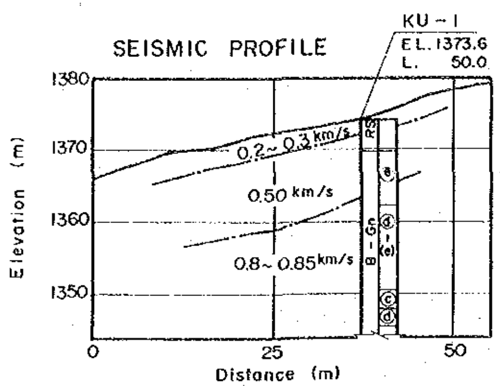
- Slope wash and alluvium covering the powerhouse site are thin and it can be expected that sound bedrock will be exposed as the foundation for the projected powerhouse.

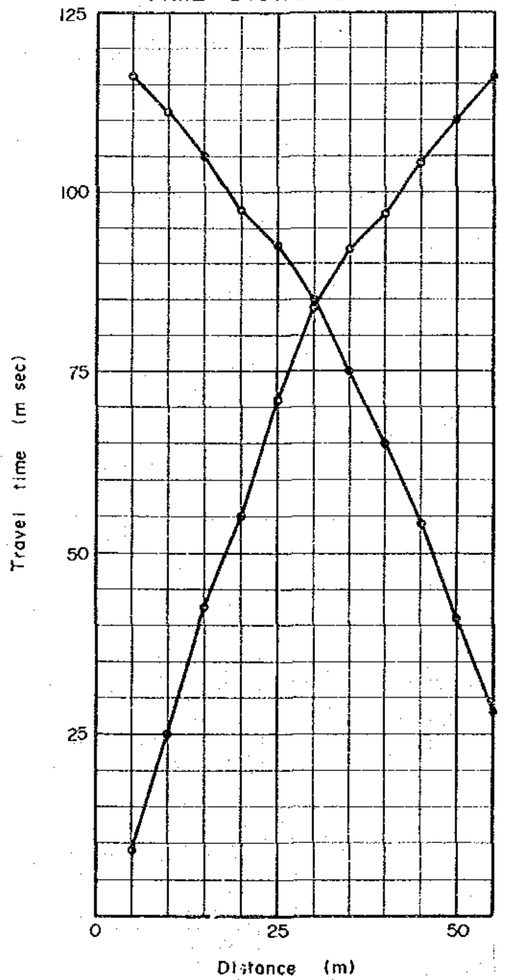
- It is considered that boring investigations will be necessary hereafter for confirming the thickness of the weathered layer at the headrace tunnel section and grasping the hydrogeological properties of the tunnel section.

LOCATION MAP OF SEISMIC PROSPECTING

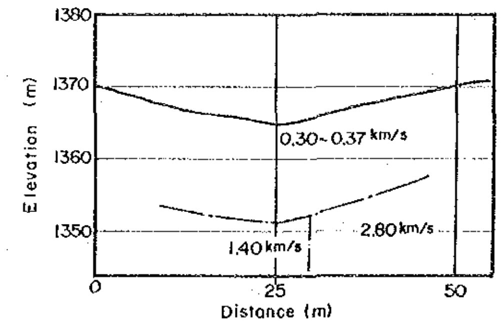


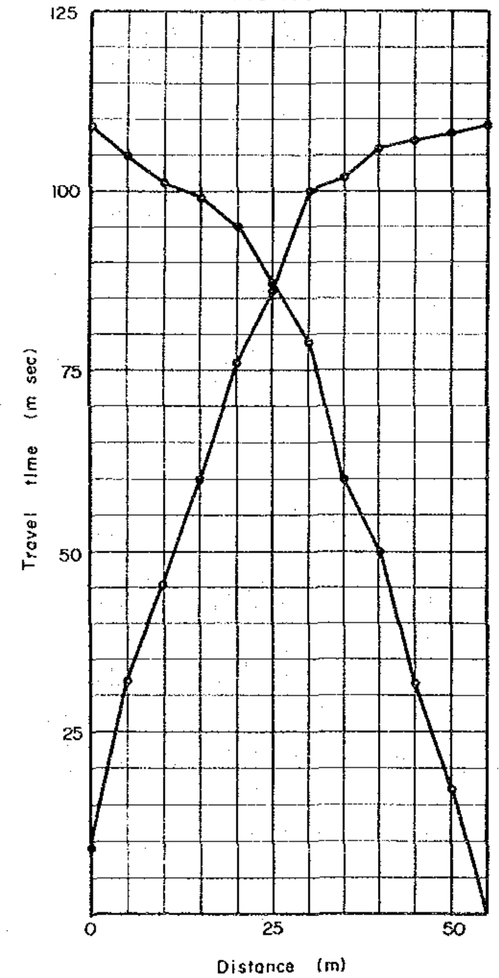
A – A
(KUS - 1)



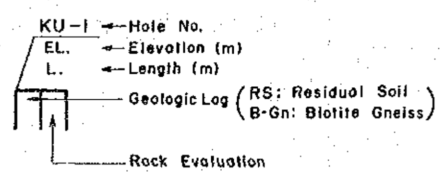


B – B
(KUS - 2)

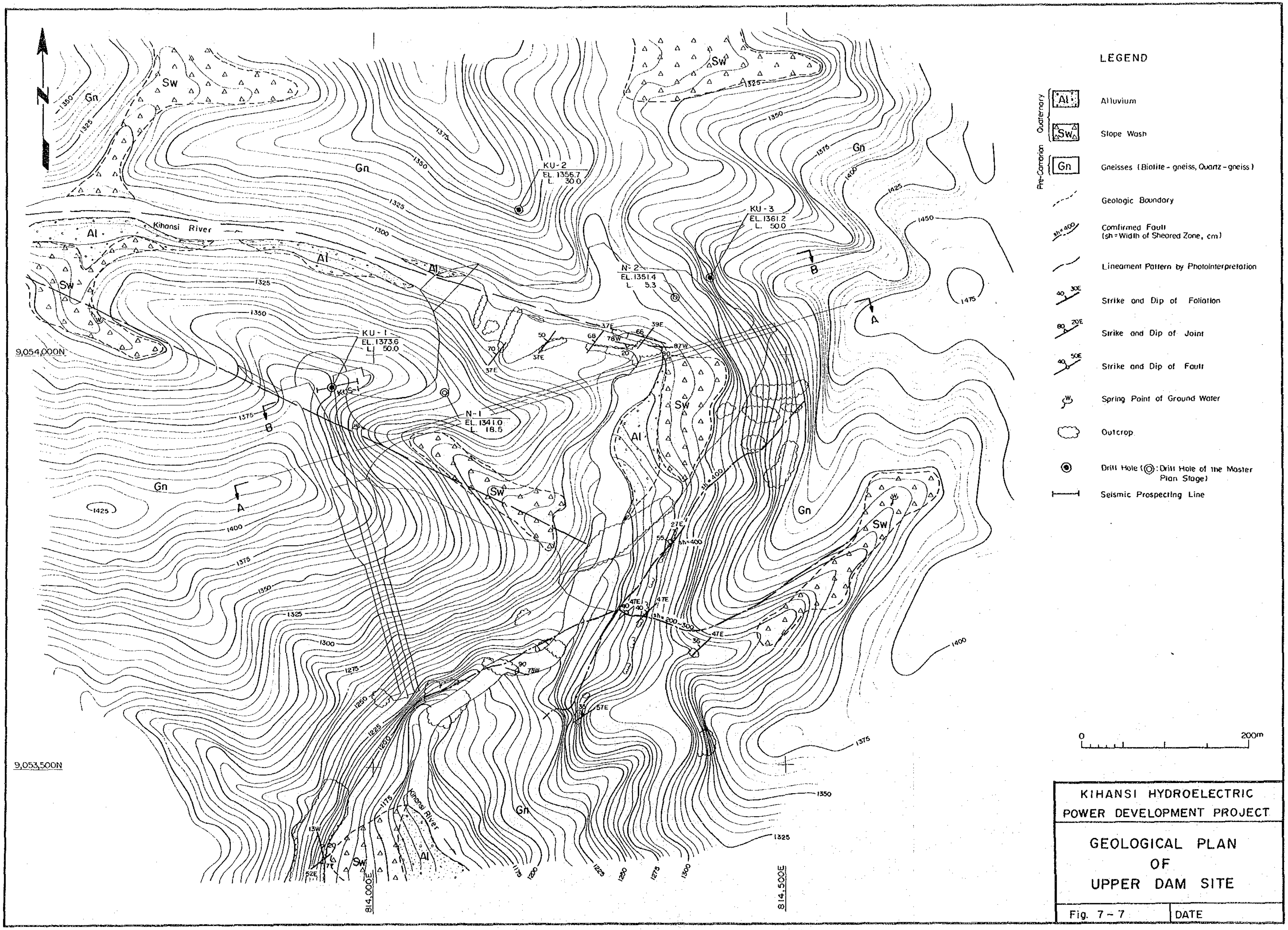




Drilling Log



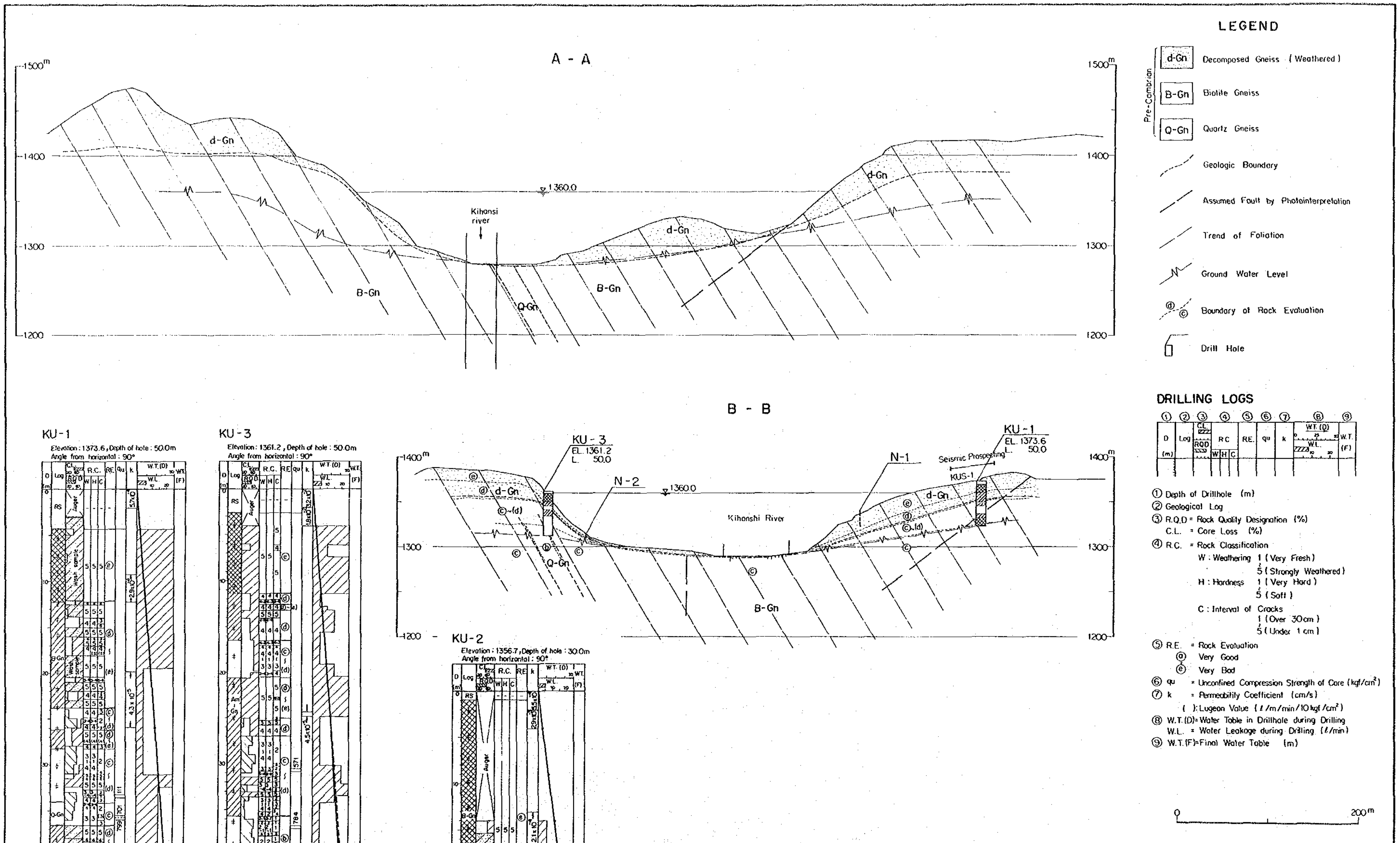
KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT	
RESULT OF SEISMIC PROSPECTING (UPPER KIHANSI RESERVOIR AREA)	
Fig. 7–6	DATE:



KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL PLAN OF UPPER DAM SITE

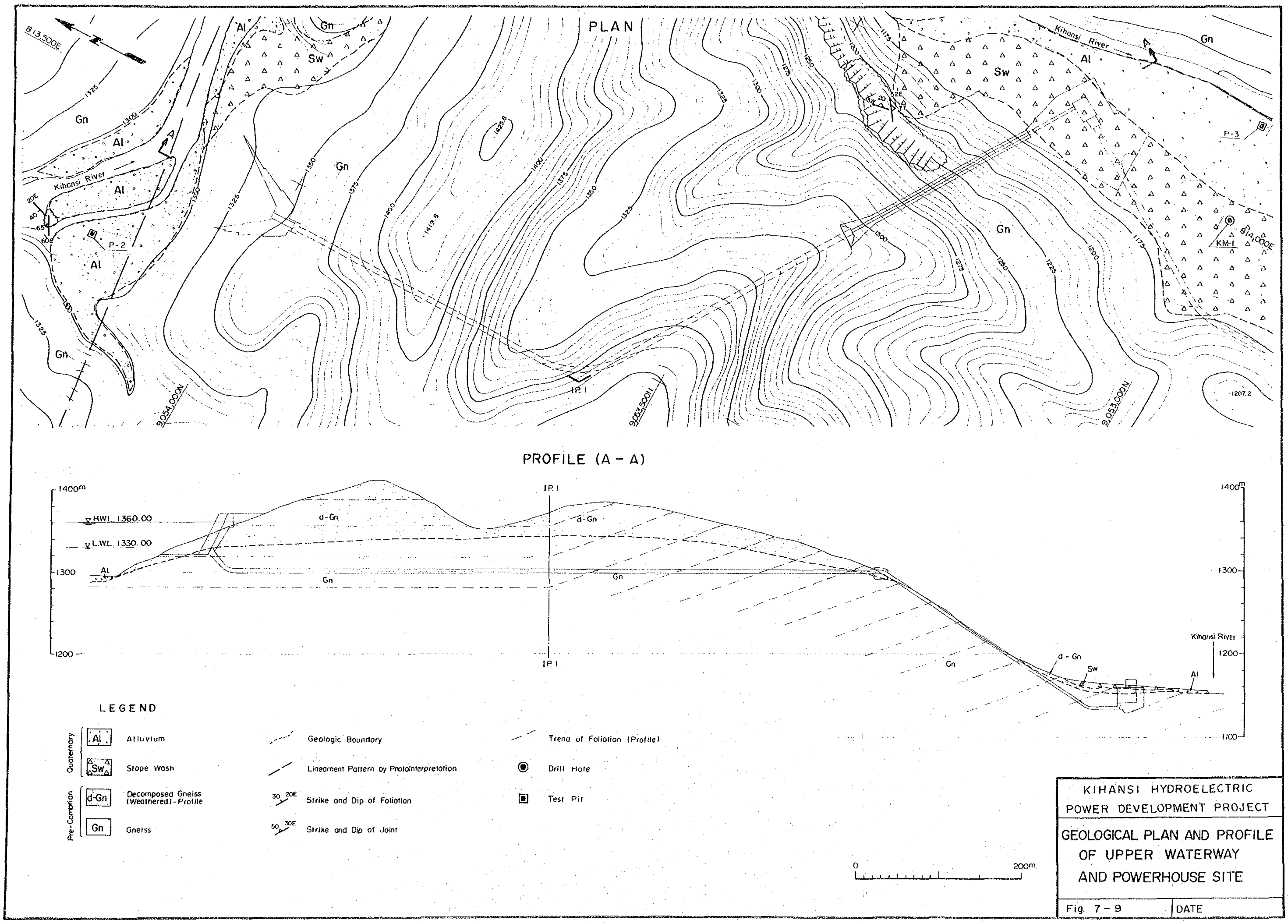
Fig. 7-7 DATE



KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL SECTION OF UPPER DAM SITE

Fig. 7 - 8 DATE :


PLAN
Kihansi River
Gn
Al
Sw
P-2
P-3
KM-1
IP.1
813,500E
814,000E
9,054,000N
9,053,500N
9,053,000N
1425.8
1419.8
1207.2
PROFILE (A - A)
1400m
1300
1200
1100
H.W.L. 1360.00
L.W.L. 1330.00
d-Gn
Kihansi River
LEGEND
Quaternary
Pre-Cambrian
Al Alluvium
Sw Slope Wash
d-Gn Decomposed Gneiss (Weathered) - Profile
Gn Gneiss
Geologic Boundary
Lineament Pattern by Photointerpretation
Strike and Dip of Foliation
Strike and Dip of Joint
Trend of Foliation (Profile)
Drill Hole
Test Pit
0
200m
KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT
GEOLOGICAL PLAN AND PROFILE OF UPPER WATERWAY AND POWERHOUSE SITE
Fig. 7-9
DATE

7.5 Geology of Lower Kihansi Project Site

7.5.1 Regulating Reservoir

(1) Topography

Lower Kihansi Regulating Reservoir of design high water level EL. 1,140 m is surrounded by gently-sloped mountains of EL. 1,200 m to 1,300 m. The distance from the dam site to the end of the backwater of the regulating reservoir is to be approximately 1.4 km, and the valley width at high water level elevation an average of approximately 100 m. The average river-bed gradient of the Kihansi River within the projected regulating reservoir area is approximately 1/50, and there are no places along the way where the river-bed gradient varies abruptly such as due to waterfalls. There are three small tributaries from the right-bank side and one from the left-bank side merging with the Kihansi River within the regulating reservoir area.

(2) Geology

The regulating reservoir area is constituted of biotite gneiss showing foliation in the N10° - 30°E, 20° - 50°NW direction roughly parallel to the flow of the Kihansi River, and alluvium distributed along the Kihansi River in very small quantities. Distribution of comparatively fresh and hard biotite gneiss is seen at the river-bed portion of the Kihansi River, and as a whole, residual soil widely covers the gently-sloped mountainsides. Alluvial deposits are thin, mainly consisting of boulders, and the content of fine-grained material is little.

(3) Engineering Geological Evaluations

Evaluations of the Lower Kihansi regulating reservoir area from the viewpoint of engineering geology may be summarized as follows:

i) Stability of Slopes

Residual soil widely covers the regulating reservoir area and the surrounding slopes, and landslide topographies and large-scale distributions of slope wash cannot be seen. Accordingly, it is judged there is little possibility of the stability of the slopes being impaired by storage of water.

ii) Watertightness

The regulating reservoir itself is of small scale, and it is judged there is no risk of leakage occurring from the regulating reservoir due to geological factors.

7.5.2 Dam

(1) Topography

The dam site is located approximately 0.9 km upstream of Kihansi Falls, at a river-bed elevation of 1,115 m. The slopes at both banks of the dam site are inclined an average 30 deg, and slopes of specific height 5 to 15 m rising from the river bed are steeply inclined at 45 to 60 deg. The right-bank slope does not have any large gullies, but at the left-bank side there are gullies at 100 m upstream and 60 m downstream of the projected dam axis, so that the left-bank side of the dam site presents a ridge topography. Vegetation is dense on the slopes at both banks, which are covered with small bushes.

The river-bed width is approximately 35 m, and the river gradient around the projected dam axis is slightly steep at 1/40. There are falls of heads 3 m and 15 m, respectively, at 200 m upstream and 140 m downstream of the projected dam axis.

(2) Geology

i) Rock Types

The dam site, as shown in Figs. 7-10 and 7-11, is constituted of biotite gneiss interbedded with an amphibolite dyke and a lamprophyre dyke, and overlying slope wash and alluvium. The biotite gneiss which is the basement rock is seen to be fresh and sound at the river bed. On the other hand, there are hardly any distributions of slope wash and alluvium, which are surface layer deposits.

ii) Geological Structure and Faults

The foliation of biotite gneiss of N7° - 27°E, 27° - 48°NW, is of a form to dip toward the right-bank side of the Kihansi River. The amphibolite and lamprophyre confirmed by boring are considered to be distributed along the direction of this foliation. Joints have been confirmed in the direction of foliation and in a direction perpendicular to it. According to aerial photo interpretations, there are lineament patterns in a direction orthogonal to the foliation at the left-bank side 100 m upstream and 60 m downstream of the projected dam axis. Faults have not been found within the limits of site reconnaissance and boring investigations, but a fractured zone of width approximately 2 m is seen at the boundary between biotite gneiss and amphibolite by boring.

iii) Weathering

According to boring investigations, weathered rock classified as Grade ⓔ to Grade ⓓ in rock evaluation is distributed at the dam site in a thickness of 4.5 m at the right-bank slope, and a thickness of 7.0 m at the left-bank slope. Deeper inside at both banks, there is slightly fresh bedrock of rock evaluation Grade ⓒ the same as the bedrock exposed at the river bed.

iv) Bedrock Strength

Excepting the weathered rock at the surface layers of the right- and left-bank slopes at the dam site, the dam site is constituted of bedrock of rock evaluation Grade ⓒ and higher. According to the results of boring core tests, the unconfined compressive strength and tensile strength of bed-rock of Grade ⓒ and higher excepting the weathered rock at this site are as given below.

Rock Type	Rock Evaluation	Unconfined Compressive Strength (kgf/cm^2)	Tensile Strength (kgf/cm^2)
Biotite gneiss	ⓒ	80 - 154	15 - 17
Amphibolite	ⓑ	1,844	152
Lamprophyre	ⓒ	2,335	105

v) Groundwater Level and Permeability

According to boring investigations made at the slopes of both banks, the groundwater levels at the two banks are not very high and are thought to be of a degree to rise only slightly above the elevation of the river bed.

The permeabilities of rocks may be summarized as follows from the results of permeability tests performed in boreholes:

Rock Evaluation	Permeability Coefficient (k: cm/s)	Lugeon Value	Remarks
Grade ⓔ - ⓓ (Weathered rock)	8.0×10^{-5} - 1.8×10^{-4}	-	k: an approximate value obtained from water level drop velocities in holes
Grades ⓒ - ⓑ (Fresh rock)	9.1×10^{-5} - 3.6×10^{-4}	7-28	According to packer tests

(3) Engineering Geological Evaluations

Evaluations of the Lower Kihansi dam site from the viewpoint of engineering geology may be summarized as follows:

- It is considered that the present dam axis location is optimum in view of the facts that waterfalls are avoided, the river width is narrowed by protrusion of the ridge at the left bank, and surface deposits do not exist.

- The weathered rock evaluated as Grade ⓔ to Grade ⓓ assumed to be distributed in thicknesses of 5 to 10 m at the surface layers of the slopes at both banks of the projected dam axis will need to be excavated and removed since it is unsuitable as a dam foundation.

- The Grade (c) bedrock deeper inside, although slightly weak in terms of strength, is judged to possess ample capability as the foundation rock of the planned concrete dam of height around 30 m.

- The permeability of the dam foundation rock is comparatively low. It is also considered possible for adequate waterstop treatment to be provided this bedrock through cement grouting of the kind normally employed, and it is judged that problems concerning waterstopping will be slight.

- However, detailed geological investigations including permeability tests of the upper parts of the slopes at both banks near the dam abutment and deep parts in the vicinity of the river bed will still be necessary hereafter.

7.5.3 Headrace and Penstock Tunnels

(1) Topography

The projected headrace and penstock tunnels have a length of approximately 4.2 km and pass the left-bank side of the Kihansi River. The route of the headrace tunnel portion is of a comparatively gentle hill topography of elevation approximately 1,200 m, while the penstock tunnel portion is of a rugged topography of continuations of steep cliffs.

The thickness of cover from tunnel to ground surface is 50 m at minimum near the middle of the headrace tunnel and 300 m at maximum at the penstock tunnel portion.

(2) Geology

i) Rock Types

The headrace and penstock tunnel route, as shown in Fig. 7-12, is constituted of gneiss as the basement rock and a surface layer of slope wash. The gneiss, besides fresh bedrock outcropped more or less continuously along the Kihansi River, is exposed at steep cliffs along the tunnel route. Slope wash, in addition to being widely distributed at the left-bank slope downstream of Kihansi Falls, is found at foots of cliffs and along gullies, although in small areas.

ii) Geological Structure and Faults

Foliation of gneiss shows a direction of N2° - 27°E, 30° - 48°NW, roughly parallel to the direction in which the tunnel extends. According to aerial photo interpretation, there are lineament patterns which intersect the direction of this foliation diagonally or perpendicularly seen at the tunnel route. The intersecting angles of these lineament patterns and the projected tunnel are from 30 deg to 90 deg, and although the true nature of these lineament patterns cannot be confirmed in the field, there is considerable possibility that they are continuous joints or faults.

Outcropping of faults has not been confirmed along the tunnel route.

iii) Weathering

Weathering of the surface layer is thick along the headrace tunnel portion where the topography is gently sloped. According to boring investigations, weathered rock evaluated as Grade ⓔ is distributed in a thickness of at least 20 m from the ground surface at the saddle portion. On the other hand, the penstock tunnel portion is assumed to have small thickness of weathering in view of the fact that outcrops of fresh bedrock have been confirmed at various places of the steeply-sloped topography.

iv) Scars

Although colluvial scars are not found at the gentle hill area of the headrace tunnel route, there are numerous scars seen at the steeply-sloped penstock tunnel route. The areas of collapse at all of the scars are small with the degree being that of surface layer soil or weathered parts having fallen and depths are small.

v) Bedrock Strength

Since the minimum cover to the ground surface for the projected tunnel is 50 m, it is considered that almost the entire section passes through fresh bedrock. Although data concerning strength of fresh rock at this route are not available, based on data obtained in the project area as a whole, fresh bedrock is estimated to have strengths of about 560 to 1,100 kgf/cm^2 in terms of unconfined compressive strength and 40 to 68 kgf/cm^2 in terms of tensile strength.

vi) Groundwater Level

According to boring investigations made at the headrace tunnel portion, the water table exists only below at least a depth of 20 m from the ground surface, and it was confirmed that the groundwater level in this vicinity is low. On the other hand, at the penstock tunnel portion, the groundwater level is assumed to be high in view of the facts that fresh bedrock is distributed at comparatively shallow parts and water is visible at the surface in most gullies.

(3) Engineering Geological Evaluations

Evaluations of the headrace and penstock tunnel route from the viewpoint of engineering geology may be summarized as follows:

- For the headrace and the penstock, it is considered that a tunnel proposal will be more advantageous than a surface proposal in view of the facts that there are many places of steeply-sloped topography and numerous scars can be seen.

- As a whole, although it is thought there are no fatal drawbacks geologically for the projected tunnel at the headrace and penstock tunnel route, it is expected there will be the following problematic points at parts.

- Weathering is thick while there is a part of the headrace tunnel which will have thin cover, but if at 50 m underground as projected, there is a great possibility that the tunnel will pass through fresh bedrock.

- However, in the event that the tunnel passes through a so-called weak bedrock layer such as a fault at the portion of thin cover, it will be necessary to provide measures such as installation of steel liners for that section.

- There is a possibility that the lineament patterns discerned in aerial photo interpretation are faults. Considered from the total length of the tunnel, the frequency at which they would be encountered is not high, but it is expected that there may be cases in which it would be unavoidable for the tunnel to pass through a section of deteriorated rock. It will be necessary for the precision of investigations from the ground surface to be improved.

- The thickness of slope wash widely distributed at the left-bank slope downstream of Kihansi Falls is not so great, and it is expected that adequate bedrock cover can be provided if at the projected tunnel depth.

7.5.4 Powerhouse

(1) Topography

The powerhouse site is located at the left-bank side of the Kihansi River approximately 3 km downstream of Kihansi Falls. There is a gently-sloped area of approximately 0.2 km^2 along the Kihansi River at this location, and the powerhouse is planned here, while in the downstream direction from this location, a tailrace tunnel is to be provided.

The powerhouse site is a gently-sloped area of an average gradient of approximately 5 deg, and because there are numerous small gullies, the area has a large number of small undulations. Vegetation is very dense with large trees and grasses covering the area. On the other hand, the slope behind the projected powerhouse site is comparatively steep, and vegetation is sparse when compared with the powerhouse site.

(2) Geology

i) Rock Types

The powerhouse site, as shown in Figs. 7-13 and 7-14, is constituted of biotite gneiss as foundation rock, and slope wash and alluvium at the surface. Biotite gneiss which is comparatively fresh is found as surface outcrops at the slope behind the powerhouse planned along the Kihansi River. The slope wash at the surface layer is widely distributed over the entire gently-sloped area of the powerhouse site, while further, alluvium is seen along gullies in the area.

ii) Geological Structure and Faults

The foliation of the biotite gneiss, although seen to vary locally, indicates a direction of N2° - 27°E, 30° - 45°NW, roughly parallel to the projected direction of the waterway. Joints are seen in various directions in relation to this foliation -- parallel, diagonally crossing, and perpendicularly crossing.

According to aerial photo interpretation, there is a lineament pattern which is fairly distinct and continuous over a long distance in the N76°W direction along the boundary between the steep and gently-sloped areas. Since this lineament pattern also passes a site which appears like a fault saddle east of the powerhouse site, there is a strong possibility that it is a fault.

iii) Weathering

According to boring investigations, there is a distribution of a weathered layer 4 m to 20 m in thickness at the powerhouse site.

The weathered layer is assumed to be thickest in the vicinity of the previously-mentioned lineament pattern, gradually becoming thinner toward the Kihansi River. As for the slope at the back, it is thought the weathered layer is thin because of a comparatively steep gradient.

iv) Bedrock Strength

Regarding strengths of the comparatively fresh bedrock underlying the weathered layer at the powerhouse site, unconfined compressive strengths of 108 kgf/cm^2 to 559 kgf/cm^2 and tensile strengths of 22 kgf/cm^2 to 32 kgf/cm^2 have been obtained.

v) Groundwater Level

According to boring investigations, the water table at the powerhouse site is high, and it is estimated to exist at around 1.5 m below the ground surface at an elevation roughly equal to the water level of the Kihansi River.

(3) Engineering Geological Evaluations

Evaluations of the powerhouse site from the viewpoint of engineering geology may be summarized as follows:

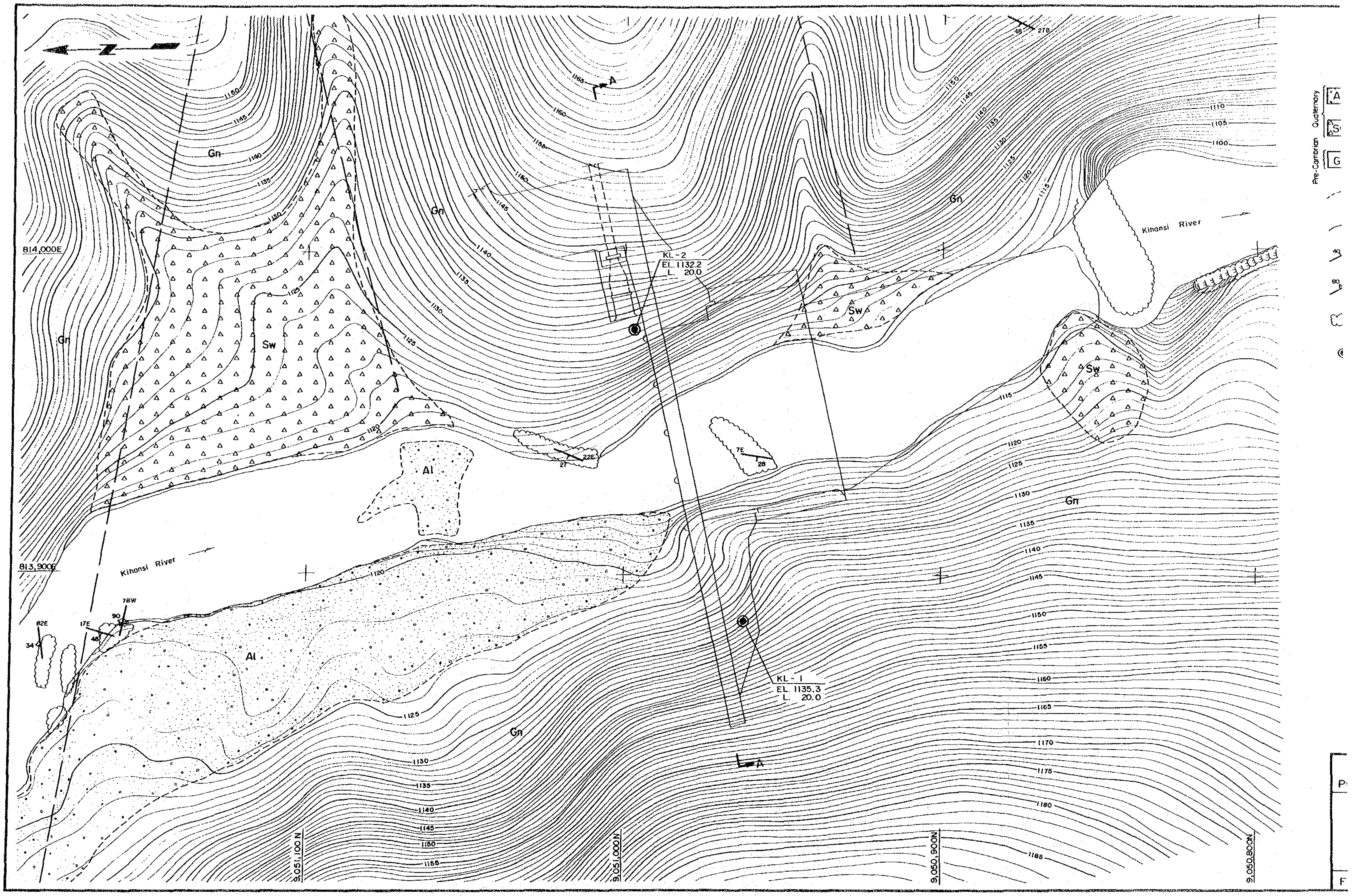
- Regarding the location for the powerhouse, it should be selected inside this gently-sloped area as there is no other suitable place from the standpoint of topography. However, there is a possibility that the lineament pattern in the N76°W direction is a fault, and it is considered desirable for this to be avoided.

- Slope wash is distributed at the projected powerhouse site, but the thickness is small, and it is expected that bedrock will be exposed at the foundation of the powerhouse.

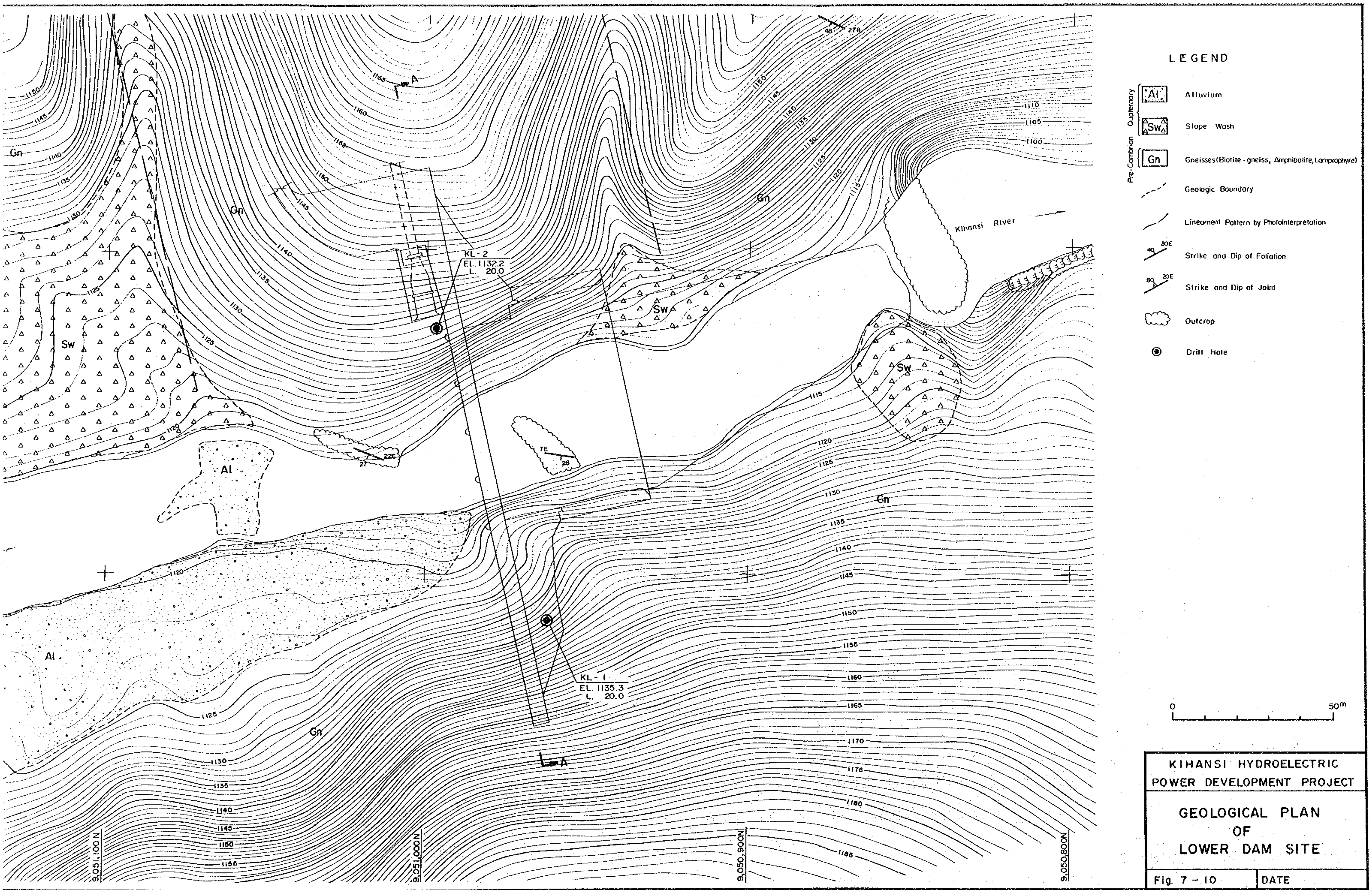
- The bedrock expected to be exposed at the powerhouse foundation is judged to be comparatively fresh and possess adequate capability strength-wise to serve as a foundation for a structure.

- Colluvial scars are seen here and there at the slope behind the powerhouse, but they are all of small scale, and it is judged there will be no concern about large-scale collapse of the slope or landsliding.

- It will be necessary hereafter to carry out investigations of the foundation part through boring at the projected powerhouse site, and diagonal boring and trenching for ascertaining the true nature of the lineament pattern in the N76°W direction.



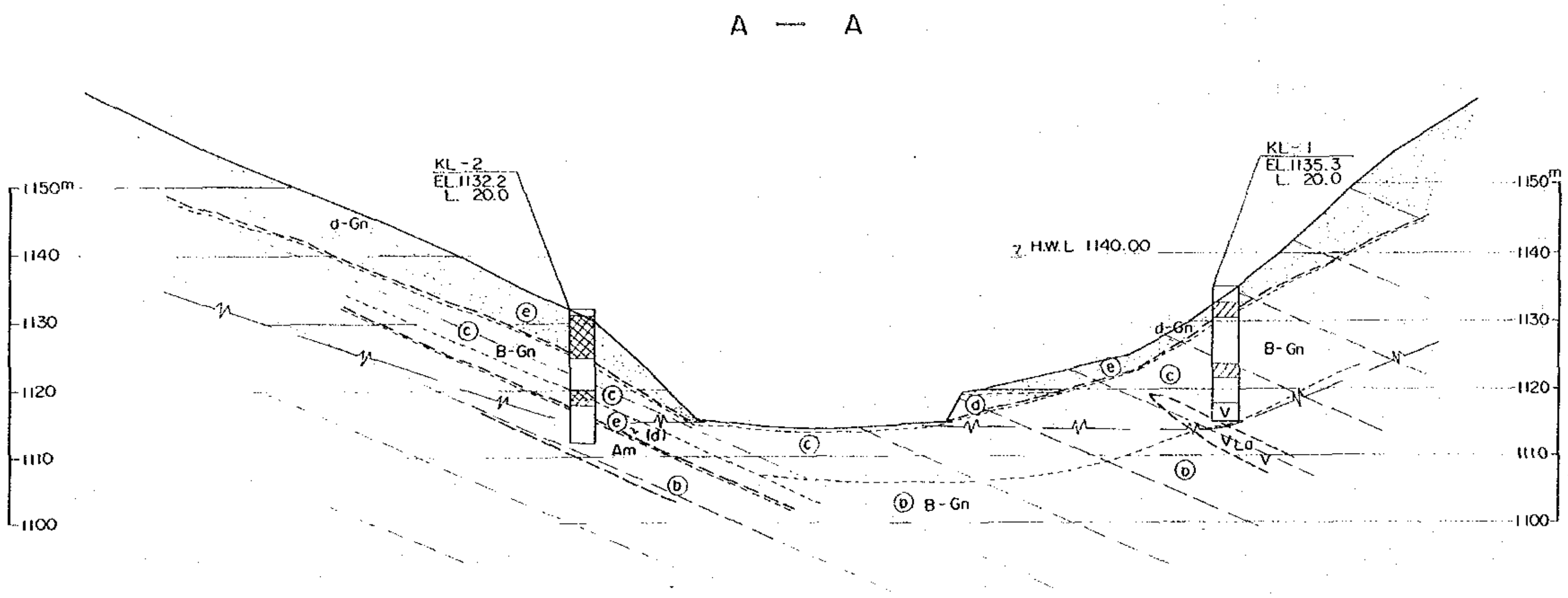
N
Gn
Sw
Al
Kihansi River
814,000E
813,900E
KL-2
EL. 1132.2
L. 20.0
KL-1
EL. 1135.3
L. 20.0
A
9,051,100N
9,051,000N
9,050,900N
9,050,800N
Pre-Cambrian
Quaternary

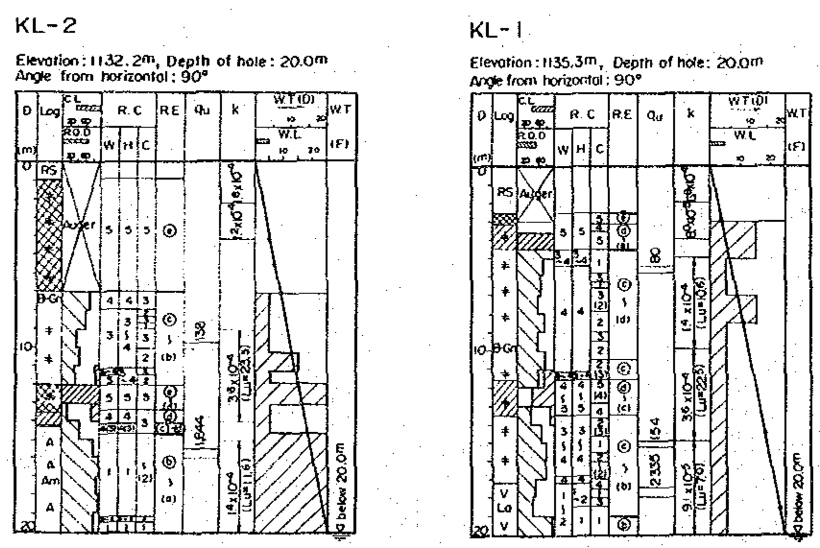


KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL PLAN OF LOWER DAM SITE

Fig. 7 - 10	DATE



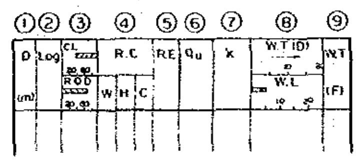


LEGEND

Pre-Cambrian

- d-Gn — Decomposed Gneiss (Weathered)
- B-Gn — Biotite Gneiss
- Am — Amphibolite
- La — Lamprophyre
- Geologic Boundary
- Trend of Foliation
- Ground Water Level
- Boundary of Rock Evaluation
- Drill Hole

DRILLING LOGS



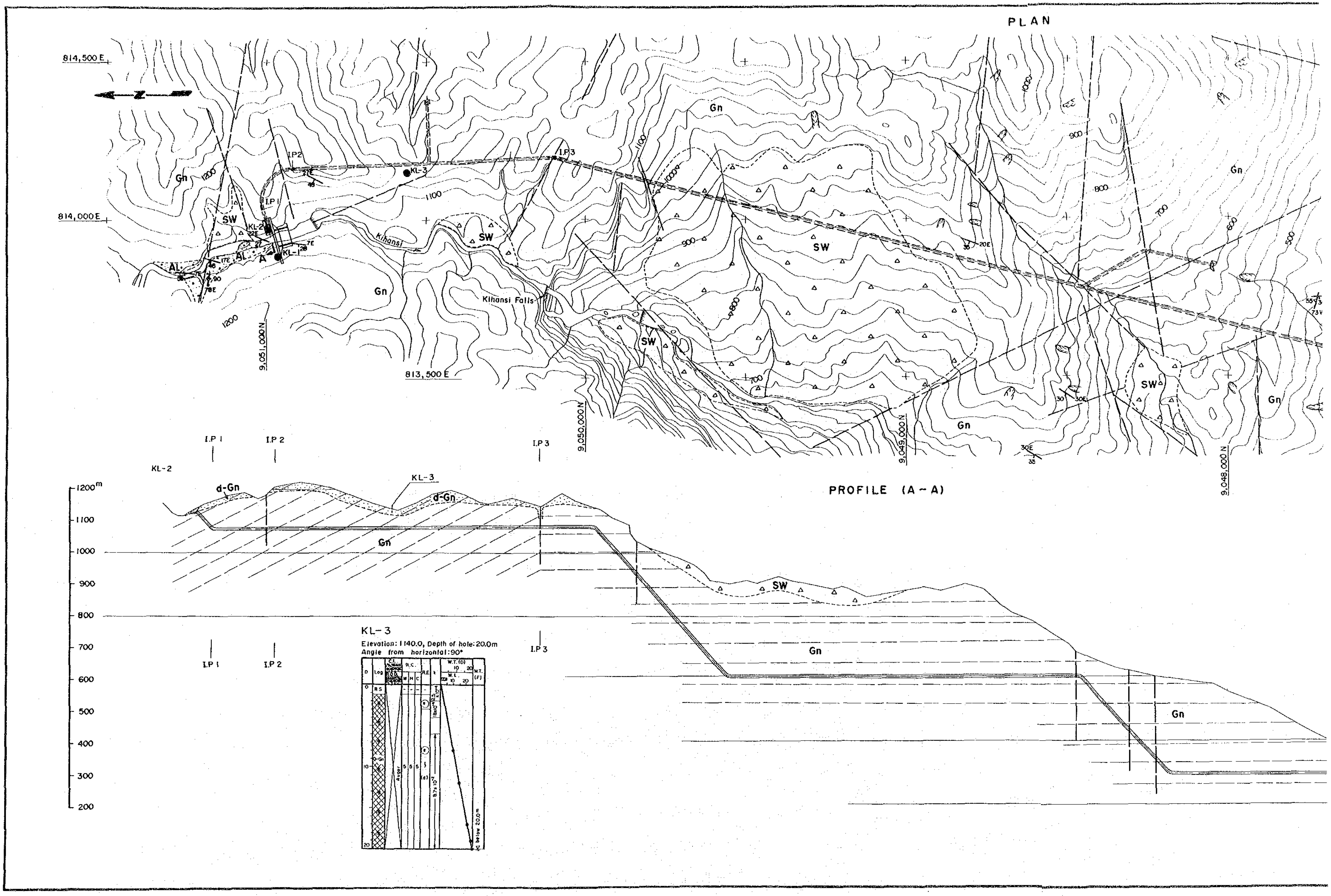
① Depth of Drillhole (m)
② Geological Log
③ R.Q.D=Rock Quality Designation (%)
C.L. =Core Loss (%)
④ R.C =Rock Classification
W: Weathering 1 (Very Fresh) ~ 5 (Strongly Weathered)
H: Hardness 1 (Very Hard) ~ 5 (Soft)
C: Interval of Cracks 1 (Over 30cm) ~ 5 (Under 1cm)
⑤ R.E. = Rock Evaluation
ⓐ Very Good ~ ⓔ Very Bad
⑥ qu = Unconfined Compression Strength of Core (kgf/cm^2)
⑦ k = Permeability Coefficient (cm/s)
( ) : Lugeon Value ($\ell/m/min/10kgf/cm^2$)
⑧ W.T.(D) = Water Table in Drillhole during Drilling
W.L. = Water Leakage during Drilling (ℓ/min)
⑨ W.T.(F) = Final Water Table (m)

0 — 50m

KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

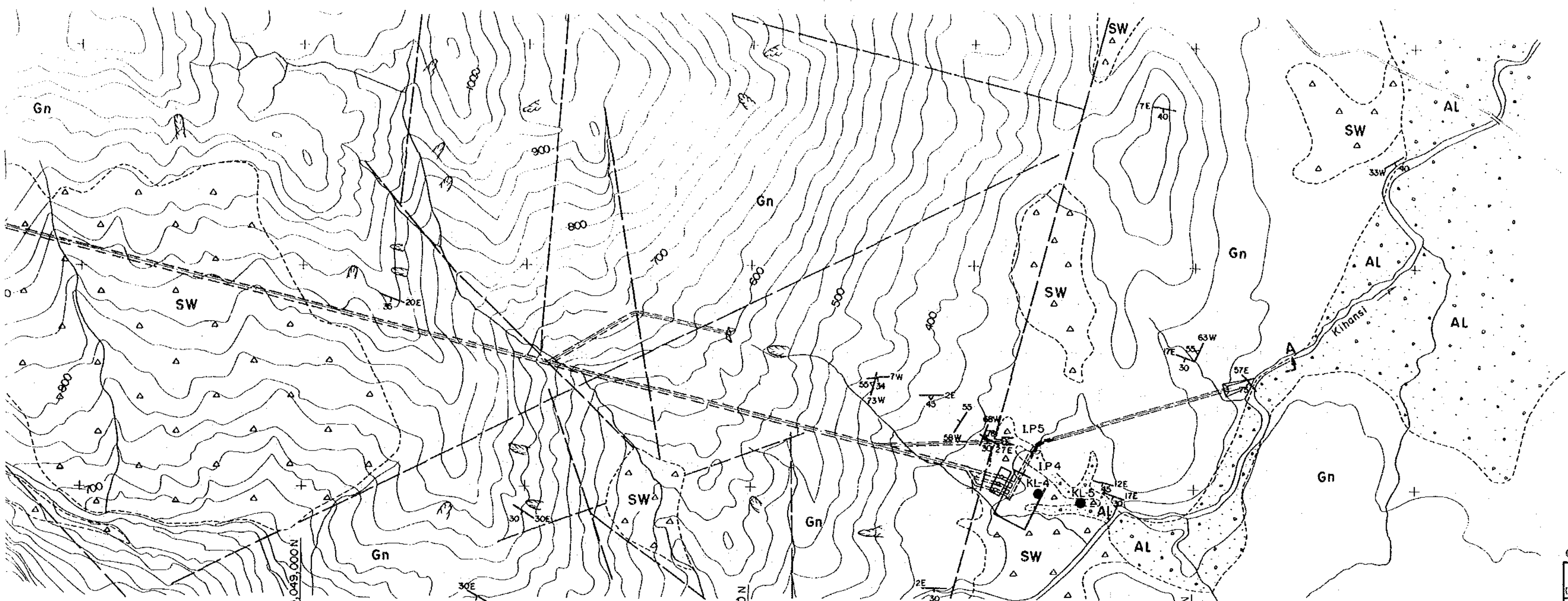
GEOLOGICAL SECTION OF LOWER DAM SITE

Fig. 7-11 | DATE



PLAN
814,500 E
814,000 E
813,500 E
9,051,000 N
9,050,000 N
9,049,000 N
9,048,000 N
N
Gn
SW
AL.
A
KL-1
KL-2
KL-3
I.P 1
I.P 2
I.P 3
Kihansi
Kihansi Falls
1200
1100
1000
900
800
700
600
500
PROFILE (A ~ A)
KL-2
KL-3
d-Gn
Gn
SW
1200m
1100
1000
900
800
700
600
500
400
300
200
KL-3
Elevation: 1140.0, Depth of hole: 20.0m
Angle from horizontal: 90°

PLAN



LEGEND

Quaternary
- AL — Alluvium
- SW — Slope Wash

Pre-Cambrian
- d-Gn — Decomposed Gneiss (Weathered) (Profile)
- Gn — Gneiss

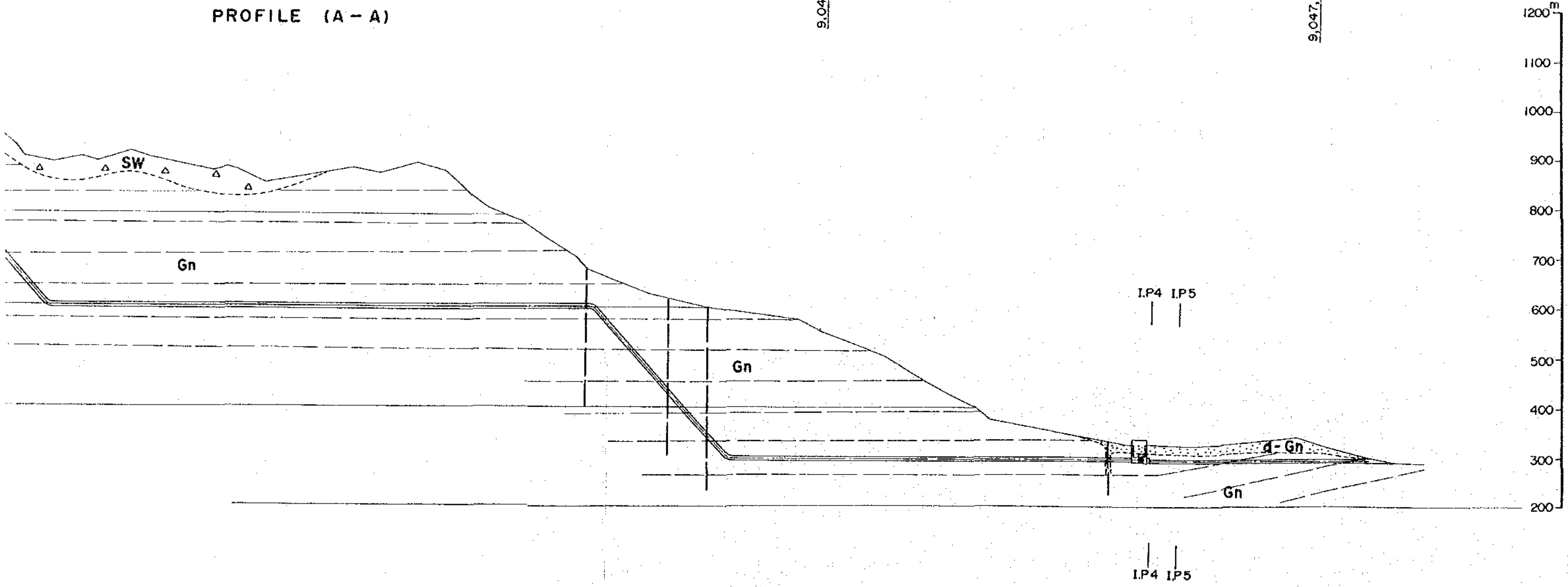
- Geologic Boundary
- Lineament Pattern by Photointerpretation
- 40 30E — Strike and Dip of Foliation
- 80 20E — Strike and Dip of Joint
- Trend of Foliation (Profile)
- Scar
- Drill Hole

DRILLING LOGS

①	②	③	④			⑤	⑥	⑦	⑧
D (m)	Log	C.L. RQD	R.C			R.E	k	W.T. (D) W.L.	W.T (F)
			W	H	C				
0									

① Depth of Drillhole (m)
② Geological Log
③ R.Q.D • Rock Quality Designation (%)
C.L. • Core Loss (%)
④ R.C. • Rock Classification
W: Weathering 1 (Very Fresh) ~ 5 (Strongly Weathered)
H: Hardness 1 (Very Hard) ~ 5 (Soft)
C: Interval of Cracks 1 (Over 30cm) ~ 5 (Under 1cm)
⑤ R.E. • Rock Evaluation
ⓐ Very Good ~ ⓔ Very Bad
⑥ k • Permeability Coefficient (cm/s)
⑦ W.T.(D) • Water Table in Drillhole durng Drilling
W.L. • Water Leakage during Drilling (ℓ/min)
⑧ W.T.(F) • Final Water Table (m)

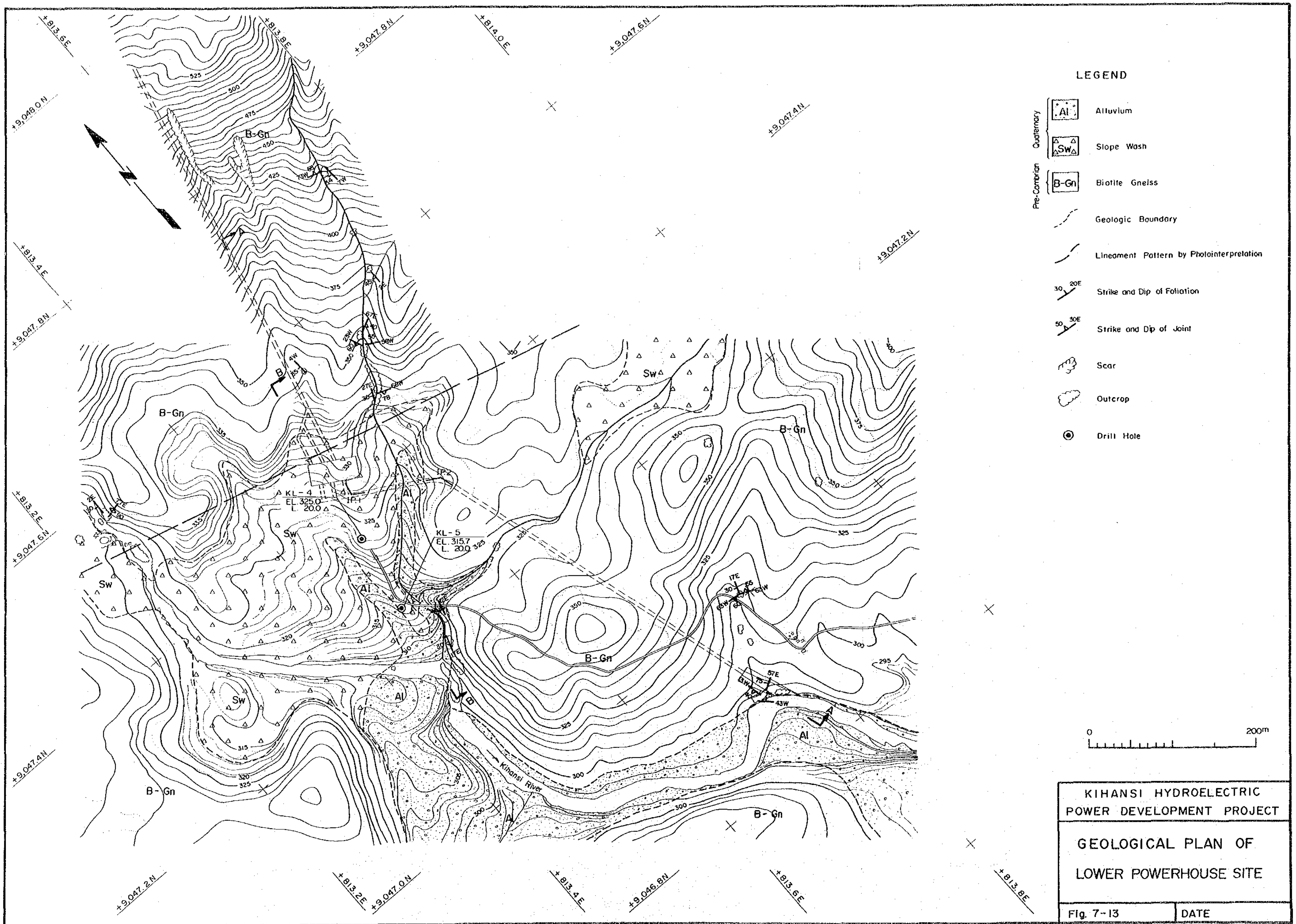
PROFILE (A-A)



KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL PLAN AND PROFILE OF LOWER HEADRACE AND PENSTOCK TUNNEL ROUTE

Fig. 7-12 | DATE:

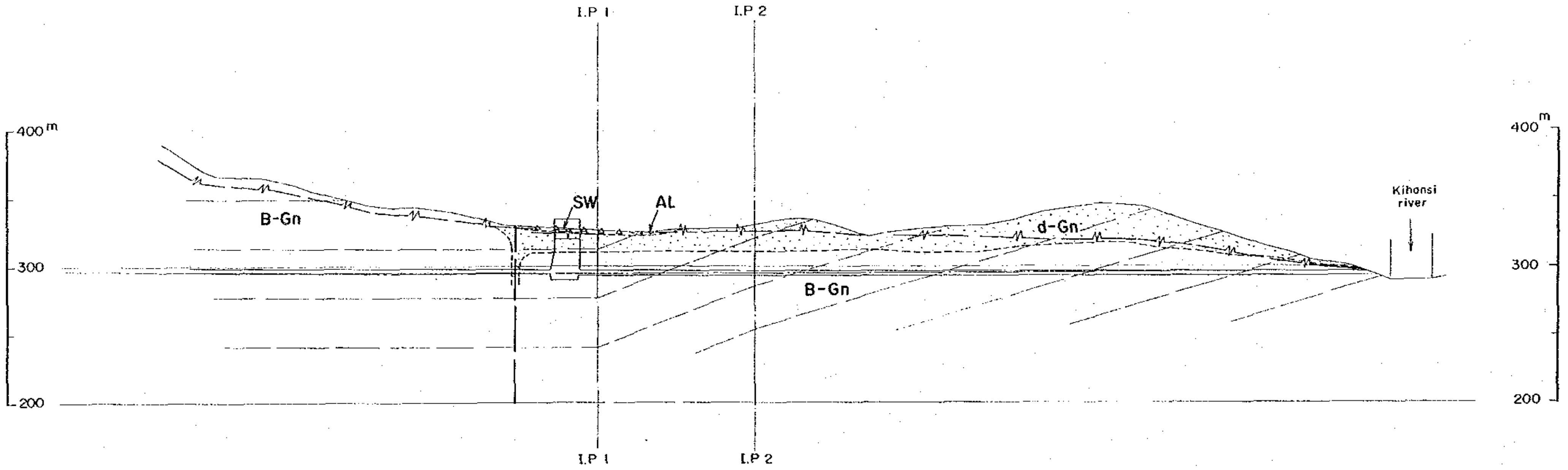


KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

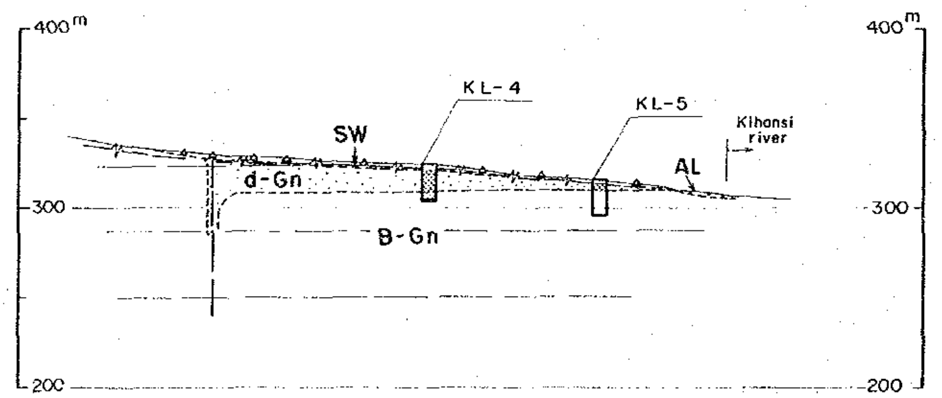
GEOLOGICAL PLAN OF LOWER POWERHOUSE SITE

Fig. 7-13	DATE

A – A

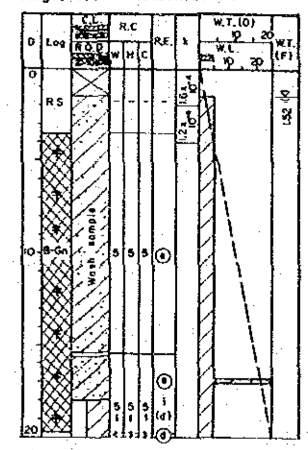


B – B



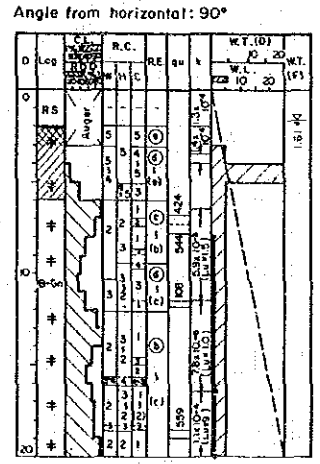
KL-4

Elevation: 325.0 ,Depth of hole: 20.0m
Angle from horizontal: 90°



KL-5

Elevation: 315.7, Depth of hole: 20.0m
Angle from horizontal: 90°



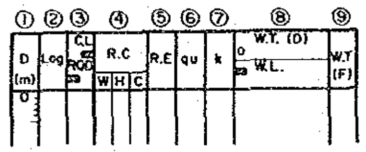
LEGEND

Quaternary
- AL — Alluvium
- SW — Slope Wash

Pre-Cambrian
- d-Gn — Decomposed Gneiss (Weathered)
- B-Gn — Biotite Gneiss

- Geologic Boundary
- Lineament Pattern by Photointerpretation
- Trend of Foliation
- Ground Water Level
- Drill Hole

DRILLING LOGS



① Depth of Drillhole (m)
② Geological Log
③ R.Q.D = Rock Quality Designation (%)
C.L. = Core Loss (%)
④ R.C. = Rock Classification
W: Weathering 1 (Very Fresh) ~ 5 (Strongly Weathered)
H: Hardness 1 (Very Hard) ~ 5 (Soft)
C: Interval of Cracks 1 (Over 30cm) ~ 5 (Under 1cm)
⑤ R.E. = Rock Evaluation (a) Very Good ~ (e) Very Bad
⑥ qu = Unconfined Compression Strength of Core (kgf/cm2)
⑦ k = Permeability Coefficient (cm/s)
(Lu): Lugeon Value (ℓ/m/min/10 kgf/cm²)
⑧ W.T.(D) = Water Table in Drillhole during Drilling
W.L. = Water Leakage during Drilling (ℓ/min)
⑨ W.T.(F) = Final Water Table (m)

0 — 200m

KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL PROFILE OF LOWER POWERHOUSE SITE

Fig. 7-14	DATE;