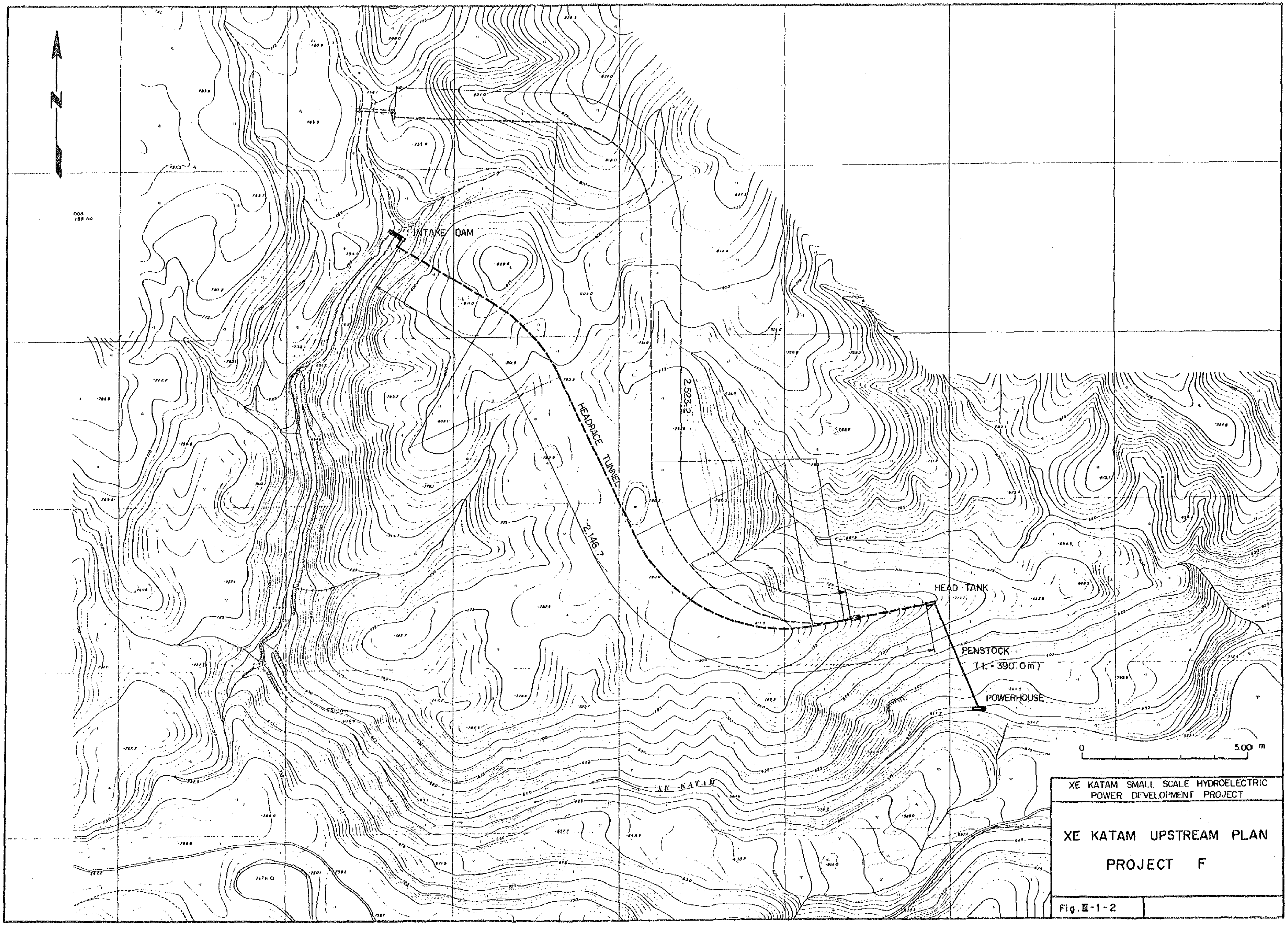

XE KATAM SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT

XE KATAM UPSTREAM PLAN

PROJECT F

Fig.III-1-2

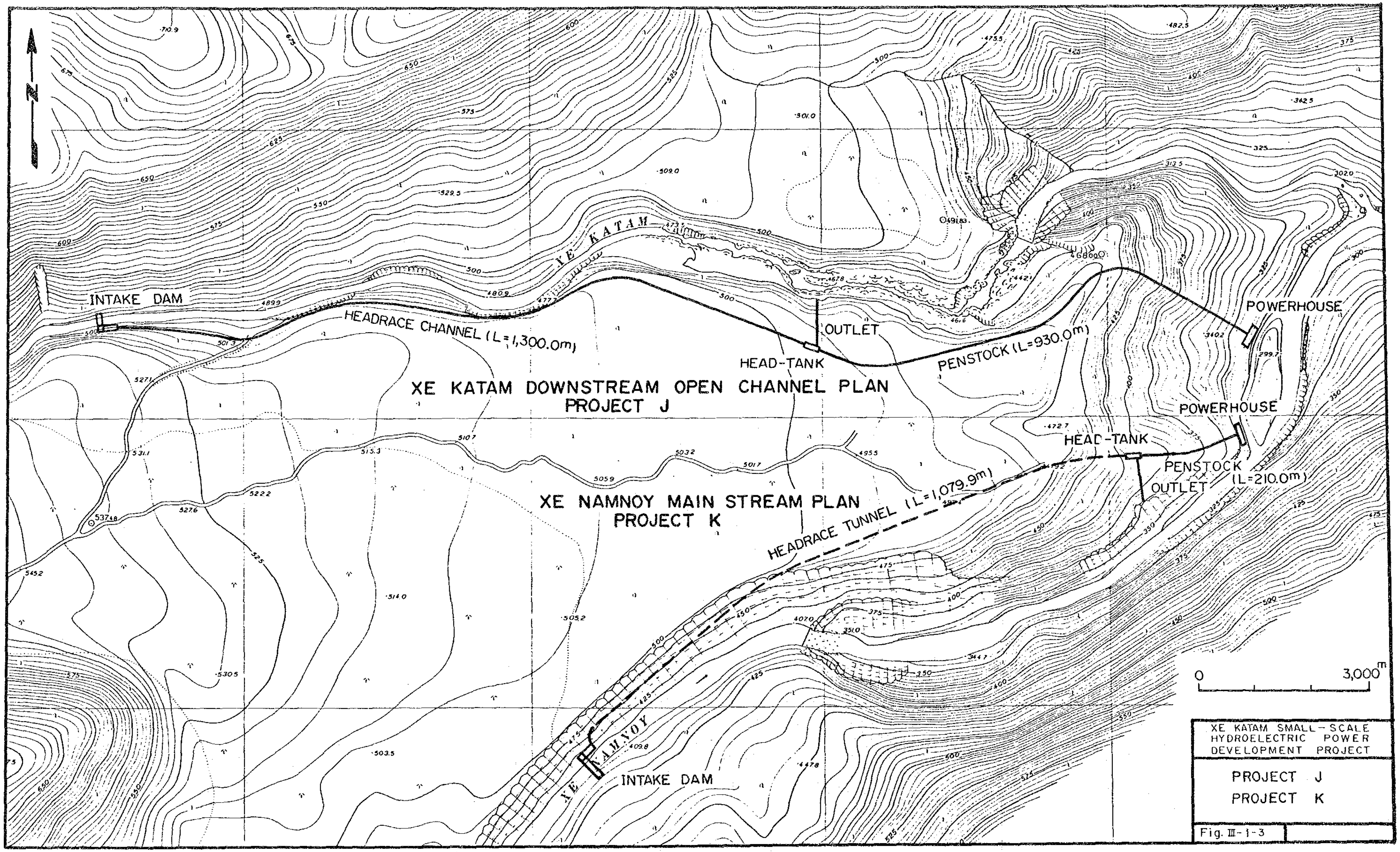
INTAKE DAM
HEADRACE CHANNEL (L=1,300.0m)
XE KATAM
OUTLET
HEAD-TANK
PENSTOCK (L=930.0m)
POWERHOUSE
XE KATAM DOWNSTREAM OPEN CHANNEL PLAN
PROJECT J
POWERHOUSE
HEAD-TANK
PENSTOCK
(L=210.0m)
OUTLET
XE NAMNOY MAIN STREAM PLAN
PROJECT K
HEADRACE TUNNEL (L=1,079.9m)
XE NAMNOY
INTAKE DAM
0
3,000m
XE KATAM SMALL-SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT
PROJECT J
PROJECT K
Fig. III-1-3

Fig.III-1-4 DURATION CURVE OF XE NAMNOY
(FOR PROJECT K)

1981−1990(MEAN)

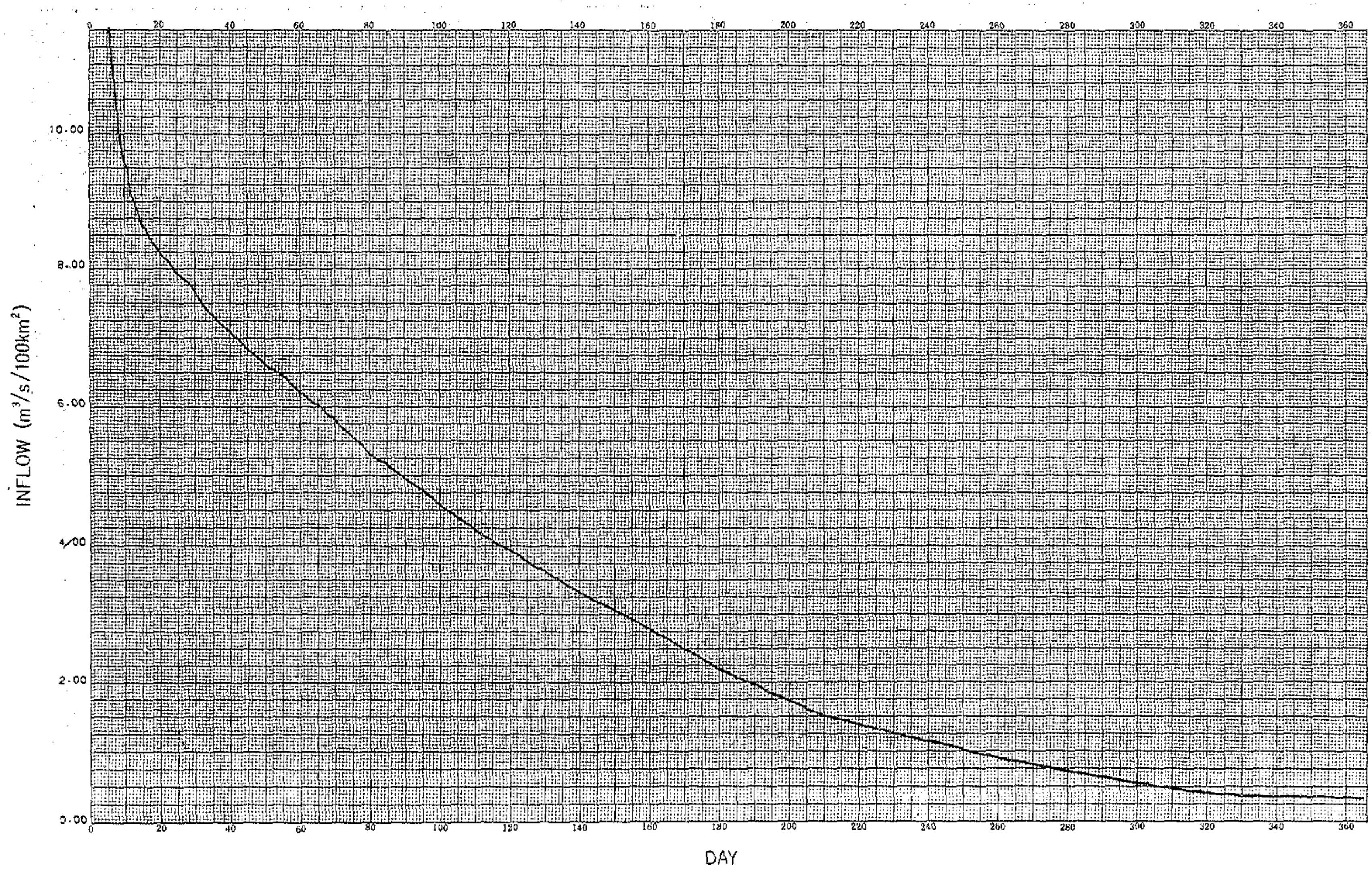

Table III-1-1 COMPARISON STUDY OF SMALL SCALE HTDROPOWER PROJECT

PROJECT	UNIT	J OPEN CHANNEL	E TUNNEL	F UPSTREAM	K XE NAMNOY
INTAKE DAM					
Height	m	4.0	4.5	5.0	5.0
Crest Length	m	34.5	47.2	57.0	60.0
Crest Elevation	m	500.0	466.5	730.0	415.0
DESILTING BASIN					
Length	m	22.0	22.0	22.0	30.0
Width	m	6.7	8.0	6.7	9.0
Depth	m	3.5	3.5	3.5	3.5
HEADRACE CHANNEL					
Type		OPEN CHANNEL	TUNNEL	TUNNEL	TUNNEL
Length	m	1,300.0	361.5	2,146.7	1,079.9
Width	m	1.8	2.3	2.3	2.8
Height	m	1.4	2.5	2.5	3.0
HEAD TANK					
Length	m	26.0		26.0	30.0
Width	m	6.2		6.2	9.9
Height		5.5		5.5	5.5
PENSTOCK					
Length	m		437.7		
Diameter	cm		150.0		
Length	m	930.0	330.0	390.0	210.0
Diameter	cm	85.0	85.0	85.0	110.0
Length	m	930.0	330.0	390.0	210.0
Diameter	cm	115.0	110.0	120.0	140.0
CATCHMENT AREA	km^2	290.0	290.0	260.0	780.0
MEAN INFLOW	m3/s	9.16	9.16	8.22	24.73
95% INFLOW	m3/s	1.00	1.00	0.91	1.95
HEADTANK WATER LEVEL	m	496.8	466.0	727.0	413.0
TAIL WATER LEVEL	m	300.0	300.0	540.0	310.0
GROSS HEAD	m	196.8	166.0	187.0	103.0
EFFECTIVE HEAD	m	190.0	160.5	184.0	101.0
MAXIMUM DISCHARGE					
FIRST STAGE	m^3/s	1.3	1.6	1.4	2.4
SECOND STAGE	m^3/s	2.7	3.2	2.8	4.9
TOTAL		4.0	4.8	4.2	7.3
INSTALLEC CAPACITY					
FIRST STAGE	MW	2.0	2.0	2.0	2.0
SECOND STAGE	MW	4.0	4.0	4.0	4.0
TOTAL	MW	6.0	6.0	6.0	6.0
ANNUAL ENERGY					
FIRST STAGE					
FIRM	GWh	13.03	11.00	11.31	17.41
MEAN	GWh	16.47	16.63	16.72	17.41
SECOND STAGE					
FIRM	GWh				2.17
MEAN	GWh	24.62	23.10	23.52	28.12
TOTAL					
FIRM	GWh	13.03	11.00	11.31	19.58
MEAN	GWh	41.09	39.73	40.24	45.53
PLANT FACTOR					
FIRST STAGE	%	94.01	94.92	95.43	99.37
SECOND STAGE	%	70.26	65.92	67.12	80.25
TOTAL	%	78.18	75.59	76.56	86.62
CONSTRUCTION COST					
FIRST STAGE	10^3US$	14,776.8	13,095.5	17,038.2	16,585.4
SECOND STAGE	10^3US$	12,005.7	10,876.9	10,629.9	12,995.8
TOTAL	10^3US$	26,782.5	23,972.4	27,668.1	29,581.2
CONSTRUCTION COST/KWh					
FIRST STAGE	US$/KWh	0.897	0.787	1.019	0.953
SECOND STAGE	US$/KWh	0.488	0.471	0.452	0.462
TOTAL	US$/KWh	0.652	0.603	0.688	0.650

Table III-1-2 COMPARISON STUDY OF PLAN E INTAKE DAM LOCATION

PROJECT	UNIT	E DOWNSTREAM	E-U UPSTREAM
INTAKE DAM			
Height	m	4.5	4.0
Crest Length	m	47.2	45.5
Crest Elevation	m	466.5	470.0
DESILTING BASIN			
Length	m	22.0	22.0
Width	m	6.4	6.4
Depth	m	2.0	2.0
HEADRACE CHANNEL			
Type		TUNNEL	TUNNEL
Length	m	361.5	361.5
Width	m	2.3	2.3
Height	m	2.5	2.5
HEAD TANK			
Length	m		
Width	m		
Height			
PENSTOCK			
Length	m	437.7	598.0
Diameter	cm	150.0	150.0
Length	m	330.0	330.0
Diameter	cm	85.0	85.0
Length	m	330.0	330.0
Diameter	cm	110.0	100.0
CATCHMENT AREA	km^2	290.0	290.0
MEAN INFLOW	m3/s	9.16	9.16
95% INFLOW	m3/s	1.00	1.00
HEADTANK WATER LEVEL	m	466.0	469.5
TAIL WATER LEVEL	m	300.0	300.0
GROSS HEAD	m	166.0	169.5
EFFECTIVE HEAD	m	160.5	163.0
MAXIMUM DISCHARGE			
FIRST STAGE	m^3/s	1.6	1.6
SECOND STAGE	m^3/s	3.2	3.1
TOTAL		4.8	4.7
INSTALLEC CAPACITY			
FIRST STAGE	MW	2.0	2.0
SECOND STAGE	MW	4.0	4.0
TOTAL	MW	6.0	6.0
ANNUAL ENERGY			
FIRST STAGE			
FIRM	GWh	11.00	11.18
MEAN	GWh	16.63	16.89
SECOND STAGE			
FIRM	GWh		
MEAN	GWh	23.10	22.89
TOTAL			
FIRM	GWh	11.00	11.18
MEAN	GWh	39.73	39.78
PLANT FACTOR			
FIRST STAGE	%	94.92	96.40
SECOND STAGE	%	65.92	65.33
TOTAL	%	75.59	75.68
CONSTRUCTION COST			
FIRST STAGE	10^3US$	13,095.5	13,748.9
SECOND STAGE	10^3US$	10,876.9	10,873.7
TOTAL	10^3US$	23,972.4	24,622.6
CONSTRUCTION COST/KWh			
FIRST STAGE	US$/KWh	0.787	0.814
SECOND STAGE	US$/KWh	0.471	0.475
TOTAL	US$/KWh	0.603	0.619

Table III-1-3 Project Feature of Finalized Plan

	First Stage	Latter Stage
Catchment Area (km^2)	290	
Mean Annual Inflow (MCM)	289	
Intake Dam		
Crest Length (m)	77	
Height (m)	8.6 (max)	
Headrace Tunnel		
Type	Pressure Tunnel	
Inner Diameter (m)	2.0	
Length (m)	342.25	
Penstock		
Type	Steel Pipe & F.R.P.	
Inner Diameter (m)	2.00 ~ 0.90 ~ 0.50 x 2	1.10 ~ 0.75 x 2
Length (m)	336.79	290.10
Powerhouse		
Type	Outdoor Type	
Width (m)	15.0	15.0
Length (m)	26.0	25.0
Turbine	H. Pelton x 2	H. Pelton x 2
Power Generation Plan		
Intake Water Level (m)	469.0 ~ 468.2	
Tail Water Level (m)	306.7	306.7
Gross Head (m)	162.3 ~ 161.5	
Effective Head (m)	159.1 ~ 158.3	#1,2 : 158.5 ~ 157.9 #3,4 : 158.0 ~ 157.2
Installed Capacity (kw)	2,000	6,000
Firm Capacity (kW)	1,400	1,400
Available Annual Energy (MWh)	16,613	40,299
Firm Energy (MWh)	12,235	12,235

2. Topography and Geology

Chapter III 2. Topography and Geology

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2. Topography and Geology

Assessments from the standpoints of geology, hydrogeology, geological engineering, construction materials, and seismicity concerning Xe Katam Project will be described in this section. Those geological data have obtained in investigations carried out from December 1990 to June 1991.

The results of geological investigations concerning this project have been put together in 1/200 to 1,5000 topographical maps regarding the "Xe Katam Tunnel Plan (E)" which is the optimum plan. For the others, the "Xe Katam Downstream Open Channel Plan (J)," the "Xe Katam Upstream Plan (F)," and the "Xe Namnoy Main Stream Plan (K)" on the Xe Namnoy River, the investigation results have been put together in 1/5,000 topographical maps and the geological maps, and the geological investigation results have been collected in appendix 2.

2.1 Outlines of Regional Topography and Geology

2.1.1 General Topography

The Xe Katam River where the intake dam is planned is approximately 40 km long and its catchment area are 290 km^2 wide. This river springs both from a mountainland of elevation around 1,700 m at the northeastern part of the Bolaven Plateau and from east of Paxsong Town at EL. 1,300 m, after which it flows south or east through a tableland of little relief of elevations from 1,000 m to 800 m. After that the Xe Katam River joins with the Xe Namnoy River at the fringe of the plateau where the river gradient becomes steep.

The upstream and midstream stretches of the Xe Katam River (the stretches upstream of a point 10 km above the confluence with the Xe Namnoy River) flows gently and its average river-bed gradient is 1/130. Downward erosion has not progressed and in many places both banks comprise hills. On the other hand, the downstream stretch of 10 km long to the confluence with the Xe Namnoy River flows swiftly and its average river-bed gradient is 1/20 with forming waterfalls of heads about 5 m and rapids everywhere. The river changes course from south to east going down mountainland having flat tops of elevation around 800 m. Especially, with two waterfalls of head 100 m and 20 m at a point 1 km upstream of the confluence with the Xe Namnoy River, the river-bed elevation of the Xe Katam River is suddenly lowered. Subsequent to this, at a point of elevation 300 m, the Xe Katam River joins with the Xe Namnoy River which had come flowing down in the northeast direction.

The downstream stretch of Xe Namnoy River jointed with the Xe Katam River has an average river gradient of around 1/100 and the flow is gentle, but in the section from 500 m to 1,600 m upstream of the confluence, the Xe Namnoy River is a swift stream of continuations of falls of maximum head 70 m and rapids. The average river-bed gradient in this section is 1/8.

The area of the confluence of the Xe Katam River and the Xe Namnoy River, surrounded by mountainland of elevations around 800 m, there is spread out a flat area of length 2 km and width 1 km, long in the east-west direction, which slopes gently down to the east from EL. 530 to 480 m. The before-mentioned Xe Katam River flows through this flat area eroding the northern side, while the Xe Namnoy River flows down the boundary between the southern-side mountainland and the flat area eroding even more severely than the Xe Katam River. The two rivers merge in the vicinity of the eastern end of the flat area forming steep cliffs such as at the waterfall of 100 m on the Xe Katam River seen here and there.

The project site is in the vicinity of the above-mentioned confluence of the Xe Katam River and the Xe Namnoy River. The intake dam is planned to be constructed on the Xe Katam River immediately upstream of the waterfalls of 100 m and 20 m. The headrace tunnel is planned in the flat area spread out on the right-bank side of the Xe Katam River. The penstock is planned on the slope at the eastern end of the flat area, and a powerhouse is planned on the left bank of the Xe Namnoy River.

2.1.2 General Geology

The project area and surroundings, as shown in Fig. III-2-1, underlain by consists of Mesozoic sandstone, Pliocene to Pleistocene basaltic lava, and Quaternary terrace deposits, talus deposits, and river deposits.

The sandstone is distributed at the mountainlands on the left bank of the Xe Katam River and the right bank of the Xe Namnoy River, and at the river bed of the Xe Namnoy below EL. 410 m. These sandstones have well-developed bedding planes which are more or less flat with slight undulations.
NEN-SWS joints were observed. The sandstone is unconformably overlain by basaltic lava. And the elevation of the plane of unconformity is lowest in the vicinity of the confluence between the Xe Katam River and the Xe Namnoy River.

The basaltic lava is mainly distributed in a form as if to fill the former valley sandwiched between the Xe Namnoy River and the Xe Katam River. For that reason the basaltic lava comprises the flat area of elevation around 500 m. In general, the upper part of one lava flow is often porous with much cracks, while the lower part is dense with few cracks. Overlying the lava flow there are cases of autobrecciated lava formed mainly of breccia in a transition from basaltic lava. The confirmed greatest thickness of basaltic lava is exceeding 140 m in the vicinity of the Xe Namnoy-Xe Katam confluence.

Terrace deposits are distributed in small areas mainly at the right banks of the Xe Namnoy River and the Xe Katam River.

Talus deposits show a trend of being distributed thickly near the boundaries between sandstone and basaltic lava, distribute on the left-bank slope of the Xe Namnoy River near the confluence with the Xe Katam River, and on the left-bank slope of the Xe Katam River.

River deposits are distributed at parts of the Xe Katam River running through and eroding the flat area of elevation around 500 m where the river gradient of the Xe Katam locally becomes gentle, and widely from the vicinity of the confluence with the Xe Namnoy River to the downstream area. In both cases, the river deposits consist of basalt and sandstone boulders, with very little fine-grained material, such as sand and silt.

2.2 Geological Investigations

2.2.1 Existing Reference Data

Existing topographical maps and geological data concerning the project area are as given in Table III-2-1.

2.2.2 Geological Investigation Works

The geological investigations of the project area and its surroundings were carried out by Landsat imagery interpretations and aerial photo interpretations. Surface geological reconnaissances, core drilling and seismic prospecting were performed at the sites of principal structures in the project area (Xe Katam tunnel plan (E)). These investigation works were carried out by the JICA Study Team with the cooperation of HEC of Laos.

The methods and quantities of investigations are as listed below.

- Landsat Imagery Interpretation

Area of interpretation:	Approximately 10,000 km^2 comprising Bolaven Plateau and surroundings
Scale of Landsat images:	1/500,000

- Aerial Photo Interpretation

Area of interpretation:	Approximately 150 km^2 including project area
Scale of aerial photographs:	1/30,000

- Surface geological reconnaissance

  Route of reconnaissance: Major gullies in project area and surroundings of structure sites

  Topographical maps used: 1/200 ~ 1/5,000

- Core drilling with permeability test

  7 drillholes, total 150 m, performed at intake dame site, headrace route, penstock route and power house site.

- Seismic Prospecting (refraction method)

  Locations of prospecting: 4 traverses on headrace route and penstock route, total 600 m

- Standard Penetration Tests

  Penetration tests: 5 pits, on penstock route, total 18 points

- Laboratory Tests

  Concrete aggregate tests: 2 locations, basaltic lava and sand

  Details of locations and quantities are given in Table III-2-2.

Table Ⅲ-2-1 List of Reference Data

Title	Remarks
1. Geological Map of Kampuchea, Laos and Vietnam, Scale 1/1,000,000	INTERGEO - 1988
2. Geological Map of The Bolaven Plateau, Scale 1/500,000	Vietnam - 1962
3. Xeset Hydropower Project Feasibility Study Report	Norconsult -1984
4. Xeset Hydropower Project Optimization Report	Norconsult -1985
5. Lower Mekong Hydrologic Yearbook	Interim Commitee for Coordination of The Lower Mekong Basin -1981 ~1988
6. The Earthquake Data File	NOAA(National Oceanic and Atomospheric Administration

Table III-2-2 List of Geological Investigations

[Drilling Work and Permeability Test]

Hole No.	Site	Coordinate N	E	Elevation(m)	Length (m)	Permeability Test (Times)
KI-1	Intake dam	1672,214.4	675,500.4	468.0	15.0	3
KI-2	Intake dam	1672,192.1	675,669.4	463.9	15.0	3
KT-1	Tunnel	1672,150.2	675,716.3	473.3	30.0	-
KT-2	Tunnel	1672,243.6	675,974.4	479.6	30.0	-
KP-1	Penstock	1672,215.1	676,141.5	361.5	20.0	-
KP-2	Powerhouse	1672,170.4	676,253.8	307.3	20.0	-
KP-3	Powerhouse	1672,302.4	676,326.6	308.5	20.0	-
Total 7 Holes					150.0	6

[Seismic Prospecting]

Line No.	Site	Coordinate		Length (m)	Note
SL-1	Tunnel	N1672,096.4 E 675,860.4	N1672,262.6 E 675,989.4	210	
SL-2	Penstock	N1672,258.8 E 675,999.6	N1672,212.8 E 676,124.6	210	
SL-3	Penstock	N1672,215.8 E 676,129.0	N1672,208.6 E 676,240.4	105	
SL-4	Penstock	N1672,211.4 E 676,202.0	N1672,170.0 E 676,254.3	75	
Total 4 Seismic prospectings				600	

[Standard Penetration Test]

Hole No.	Site	Coordinate N	E	Elevation(m)	Length (m)	Penetration Test (Times)
P-1	Penstock	1672,215.0	676,147.0	360.0	2.3	5
P-2	Penstock	1672,198.2	676,205.9	336.5	2.3	4
P-3	Penstock	1672,185.4	676,234.2	318.7	2.3	4
P-4	Powerhouse	1672,169.2	676,255.2	307.3	2.3	4
P-5	Powerhouse	1672,199.4	676,273.4	306.2	0.97	1
Total 5 Pittings					10.17	18

[Laboratory Test]

Test	Quantity	Test Item
Concrete aggregate test	2 samples	Specific gravity, absorption test, grain-size analysis, abration loss test, etc

2.3. Geology of Project Sites (Xe Katam Tunnel Plan (E))

The two intake dam site of Upstream Site (E-U) and Downstream Site (E-D) are compared and studies.

2.3.1 Upstream Intake Dam Site (E-U)

(1) Topography

The intake dam is planned at a site 240 m upstream of a cascade of head approximately 20 m. The width of the river bed is approximately 45 m in the vicinity of the dam axis. The right-bank of the intake dam site is a steep cliff up to a height of 6 m from the river bed following which, after once becoming flat, it becomes a slope inclined 40 deg. On the other hand, the left-bank side has a continuation of a slope of about 40 deg from the river bed to a height of approximately 30 m. The flow forms rapids the downstream of the dam axis while the upstream of dam axis is slightly more gentle. Flood marks are recognizable at heights of about 2 to 3 m above the river bed.

(2) Geology

The geology of the intake dam site, as shown in Fig. III-2-2, consists mainly of basaltic lava and autobrecciated lava interbedded locally at places, and river deposits which overlie them at parts.

At the dam site and its surroundings, there are outcrops of the bed rock at the river bed and on the slopes on both banks, and other than autobrecciated lava of thickness approximately 3 m seen at part of the foot of the right-bank slope, they are of basaltic lava.

River deposits are distributed from the middle of the river bed to the left-bank side.

Basaltic lava is fresh and hard, but there are cracks developed at the surface, and the surface is porous. The autobrecciated lava has been weathered and presents a yellowish-gray color, and is slightly softer than the basaltic lava. This autobrecciated lava consists of basaltic breccia of diameters 3 to 5 cm and lava filling the interstices, while voids can be seen at parts. The autobrecciated lava has less resistance to weathering and permeation of ground water than lava, and is seen to have a slightly inferior lithological character.

Regarding river deposits, so far as seen at the ground surface, they are almost all of basalt gravels of various sizes, includes no fine materials such as sand and silt. The thickness of the deposits is estimated to be about 2 m at maximum from the outcrops and topography in the vicinity.

In Drillhole KI-1 on the river bed, autobrecciated lava beds interbedded in basaltic lava were confirmed at depths down to 1.24 m, between 7.1 and 7.7 m, and 10.5 and 11.7 m. According to permeability tests conducted in this hole, the Lugeon values (injection pressure less than 10 kg/cm^2) of the basement rock are between 1.1 and 7.5. The water levels in Drillhole KI-1 were 0.3 m depth when drilled at 10 m depth and fell 11.3 m depth at depth of 15 m drilling. This suggests that the saturated groundwater level will not coincide with the present river water surface.

(3) Geotechnical Evaluations

- Slope failures and landslides are not observed at either bank in the vicinity of the intake dam site, while surface soils are estimated to be thin, and it is thought there will be no problem about stability of the slopes.

- River deposits are distributed at the middle part of the river bed in the vicinity of the intake dam, and the thickness is estimated to be thin judging by the condition of outcrop distribution in the surroundings. The basaltic lava to be the foundation rock for the dam and the slightly weathered tuff breccia are both hard, and it is thought there is ample bearing power as a foundation for an intake dam several meters in height.

- Judging from the Lugeon values of 1.1 to 7.5 of the foundation rock obtained in permeability tests in Drillhole KI-1, the permeability of the foundation rock is thought to be in a range that ordinary treatment will suffice, but attention should be paid that water level in the drillhole falls 11.3 m rapidly when drilling between 10 and 15 m depth. It is necessary for further detailed investigations to be made concerning the reason for the water level in Drillhole KI-1 to be lower than the present river water surface.

2.3.2 Downstream Intake Dam Site (E-D)

(1) Topography

The intake dam is planned to be provided at a site (150 m downstream from the Upstream Proposal site (E-U)) 80 m upstream of the cascades of head approximately 20 m seen at a point approximately 0.9 km upstream on the Xe Katam River from the confluence of the Xe Katam River and the Xe Namnoy River. The right-bank slope at the intake dam site is about 25 deg, and a terrace of width approximately 10 m is seen at around a height of 12 m (EL. 476 m) from the river bed. The left-bank side has a continuation of a slope with an inclination of approximately 35 deg, and there are dense growths of bamboo at parts. The river-bed width is about 45 m in the vicinity of the dam axis, and there are no large differences in river width both upstream and downstream. Rapids are formed at both upstream and downstream of the dam axis, with the river-bed gradient about 1/25.

Flood marks are seen to heights of approximately 2 to 3 m from the river bed.

(2) Geology

The geology intake dam and its vicinity as shown in Fig. III-2-2, III-2-4 and III-2-5 consists of basaltic lava, and talus deposit covering it at parts.

Basaltic lava is outcropped at almost the entire surface of the river bed where rapids are formed above and below the vicinity of the dam axis. The basaltic lava is of a blackish-gray color and is fresh and hard, but it is porous with many pores. Cooling joints of the lava are observed at the surface in a crazed pattern at spacings of 10 to 20 cm, but most cracks are tight at the interior of the rock. The flow structure of the lava is seen to be parallel to or diagonally intersecting with the direction of the river.

Strongly weathered basaltic lava or distributed at the left-bank slope in the vicinity of the dam axis. The strongly weathered basaltic lava has become red in color and is softened. The thickness of the strongly weathered layer is estimated to be thin since outcrops of comparatively fresh basaltic lava are observed seen in the neighborhood. On the right-bank slope, there are talus deposits of thickness about 2 m composed by formed from basalt gravels of diameters 10 to 40 cm.

Drillhole KI-2 at the foot of right-bank slope at the intake dam site, hard basaltic lava exists down to more than 15 m depth, and the permeability is 3.5 to 6.7 in terms of Lugeon value. However, the water level in this hole during drilling fell as drilling progressed, similarly to the previously-mentioned Drillhole KI-1. That is, the groundwater level was 1.0 m in drilling to a depth of 6.0 m, 3.4 m in drilling to 10 m, and 11.1 m in drilling to 15 m.

(3) Geotechnical Evaluations

- Slope failures and landslides are not observed at the slopes on both banks in the vicinity of the intake dam site, while the talus deposit and strongly weathered portions of basaltic lava are estimated to be thin, and it is thought there will be no great problems regarding slope stability

- Fresh and hard basaltic lava is distributed at the foundation of the dam site and it is thought there will be no problem about bearing power as a foundation for an intake dam several meters in height.

- Regarding the permeability of the foundation rock for the intake dam, it is thought to be in a range allowing ordinary treatment judging by the results of permeability tests at Drillhole KI-2, but similarly to the case of the previously-mentioned foundation rock at the upstream intake dam site, attention should be paid to the fact that the water level in Drillhole KI-2 fell rapidly during drilling between drillhole depth of 10 m and 15 m. It is necessary for further detailed investigations to be made concerning the cause of the lower water level in Drillhole KI-2 compared with the present river water surface.

2.3.3 Headrace Route

(1) Topography

Both the Upstream Route (E-U) and the Downstream Route (E-D) are planned with open canals for approximately 250 m and 100 m from their respective intakes. Downstream from these points are exactly the same routes and a tunnel of approximately 340 m long is planned.

The open canal sections are planned along the right-bank river bed of the Xe Katam River, which the river-bed gradient is about 1/40. The tunnel is planned along a flat ridge of elevation approximately 480 m and width from 30 to 100 m sandwiched between the Xe Katam River and Xe Namnoy River.

(3) Geology

The open canal sections and the tunnel section consist of basaltic lava as shown in Fig. III-2-2.

Fresh and hard basaltic lava is distributed at the open canal section. The basaltic rock is distributed also along the tunnel route. Drillhole KT-2 located near the end of the flat ridge extending in the northeast direction has provided data below.

Depth from Ground Surface	Condition of Bedrock
0 to 1.7 m	Laterite, colored red. Clayey to silty.
1.7 to 11.5 m	Strongly weathered basalt, colored roughly brownish gray. Weathered at crack surfaces and to the interior, and soft.
11.5 to 23.0 m	Slightly weathered basalt, colored gray. Weathered to brown color at crack surfaces and susceptible to separation along crack planes.
23.0 to 30.0 m	Basalt, generally fresh and hard.

The result of seismic prospecting performed along the tunnel route is summarized as Table III-2-3.

Table III-2-3 Results of Seismic Prospecting along the Tunnel Route

Velocity Layer	Depth from Surface	Velocity of Primary Wave	Note
V_1	0 ~ 2.9 m	140 ~ 190 m/sec	-
V_2	1.3 ~ 6.5 m	420 ~ 1,250 m/sec	-
V_3	under 5 m	1,100 ~ 3,700 m/sec	-

The V_1 velocity layer corresponds to the laterite, and V_2 corresponds to the strongly weathered basalt.

The groundwater level measured in dry season (Mar. 24, 1991) in Drillhole KT-2 after completion of drilling was 28.2 m below (EL. 451.4 m) the mouth of the hole, close to the depth of the hole bottom.

Outcrops of basaltic lava weathered along cracks are observed at the inlet and outlet of the tunnel.

(3) Geotechnical Evaluations

- The earth cover for the tunnel is in a range from grand surface to depth of 23 m, and it is expected that slightly weathered basalt and partially strongly weathered basalt will be found along the tunnel route. Since the weathered basalt is liable to separate along crack planes, it will be necessary for attention to be paid when driving the tunnel.

- The bedrock along the tunnel route, judging from the condition of the bedrock confirmed at Drillhole KT-2, has high permeability, and the groundwater level falls considerably in dry season (estimated to fall below the tunnel elevation), whereas it is estimated that there will be wet conditions in rainy season.

2.3.4 Penstock, Powerhouse Site

(1) Topography

The penstock is planned along a convex slope on the leftbank of the Xe Namnoy River of specific height of approximately 170 m. The powerhouse is planned on the left bank of the Xe Namnoy River downhill of the penstock.

The gradient of upper slope above elevation 370 m is 40 to 50 day and that of lower slope below elevation 370 m is 20 to 30 deg.

The slope from EL. 310 to 370 m is wider the lower the elevation ,and the slope becomes talus like.

Further, on this lower slope, there are gullies thought to have surface water during the rainy season observed at both sides of the penstock route, and some of these cut diagonally across the penstock route. These gullies are depths of 0.5 to 2 m and widths of 0.5 to 1.5 m.

A terrace of width 20 to 30 m and length 150 m formed along the Xe Namnoy River is observed at the end of the convex slope. The surface of the terrace is at an elevation of approximately 305 m, and is approximately 3.5 m above of the bed of the Xe Namnoy River. Flood marks can be recognized on this terrace cliff up to a height of approximately 2 m from the river bed.

The powerhouse and the appurtenant structures are planned mainly on this terrace.

Slope failures and landslides are not seen in the area to be passed by the penstock route.

(2) Geology

The penstock route, the powerhouse site, and their surroundings, as shown in Fig. III-2-3, are underlain by Mesozoic sandstone, basaltic lava, talus deposit, and terrace deposits.

Weathered basaltic lava is distributed at the steep upper slope above EL. 370 m on the penstock route, and talus deposit is distributed at the lower slope.

Although there remains gray-colored hard and fresh rock, weathering has progressed as a whole along cooling joints of lava, which is easily separable. The degree of the abovementioned weathering is more progressed at porous parts of the basaltic lava. More weathered porous portions and comparatively fresh dense portions are distributed alternatingly at intervals of 5 to 10 m along the penstock route.

Talus deposit are distributed along the penstock route at the slope below EL. 370 m, and are composed of basalt and sandstone gravels of particle diameters 10 to 40 cm and a sandy matrix. The thickness of talus deposit according to Drillhole KP-1, is 13.9 m. Further, the N-value of the talus deposit at depth of 0 to 2.3 m according to the standard penetration tests is 5 to 18, average is 11.

The results of seismic prospecting performed along the penstock route may be summarized as Table III-2-4.

Table III-2-4 Results of Seismic Prospecting along the Penstock Route

Velocity Layer	Section of EL.370 to 480 m		Section of EL.310 to 370 m	
	Depth from Surface	Velocity of Primary Wave	Depth from Surface	Velocity of Primary Wave
V_1	0 ~ 2.3 m	160 ~ 230 m/sec	0 ~ 2.4 m	140 ~ 220 m/sec
V_2	1.9 ~ 8.0 m	1000 ~ 1700 m/sec	1.6 ~ 10 m	710 ~ 1430 m/sec
V_3	under 5 m	2200 ~ 3700 m/sec	under 6 m	2800 ~ 3300 m/sec

Terrace deposits are distributed at the powerhouse site. According to Drillhole KP-2 provided from on top of the terrace, the terrace deposits are mainly composed of sand containing more than about 30% of sandstone gravels of 1- to 3-cm diameter. The N-values of these terrace deposits according to standard penetration tests are 8 to more than 50. Deeper than 4.7 m comprises basement rock of Mesozoic sandstone. The thickness of the terrace deposits is estimated at 3.5 m to 4.8 m according to the drillhole and the reconnaissances.

Sandstone has been confirmed to exist in the abovementioned drillhole and at the river bed in front of the powerhouse site. The sandstone is gray in color, and is a fresh and hard rock with quartz and feldspar as its principal constituent minerals. These constituent minerals make up alternations of fine-grained parts and medium-grained parts at intervals of 10 cm or more, the strikes and dips of which are roughly horizontal. Joints of strike N20°E and dip 90° are seen at 1- to 3-m spacings in this sandstone.

(3) Geotechnical Evaluations

- Weathered basaltic lava is distributed at the steep upper slope above EL. 370 m of the penstock route, but it possesses adequate bearing strength as the foundation rock for the penstock, and it is thought there will be no problem.

- It is estimated that talus deposit is distributed in thicknesses of 6 to 14.0 m at the gentle slope of the penstock route below EL. 370 m. And there are small gullies crossing the penstock route. This talus deposit is composed of sand-gravel and average N-value is 11. The abovementioned, the design of penstock should be paid attention.

- Landslides and slope failures area are not observed at the slopes along the penstock route and the powerhouse site, and the slopes are stable.

- Terrace deposit which the thickness is 3.5 m to 4.8 m is distributed at the powerhouse site. N value of the terrace deposit is from 8 to more than 50. Sandstone underlie terrace deposit, therefore the foundation of the powerhouse is suitable to be set the sandstone.

2.4 Concrete Aggregates

2.4.1 Test Quantities and Test Items

The locations where samples were collected for laboratory tests of concrete aggregates are shown in Fig. III-2-1 and Fig. III-2-6. The test quantities and test items of the samples collected are given in Table III-2-5.

As shown in Fig. III-2-1 and Fig. III-2-6 crushed stone materials for concrete aggregates were collected from river-bed gravels (basalt, ①) at the downstream part of the Xe Katam River, while fine aggregate was collected from deposits (sand, ②) in the Mekong River in the vicinity of Pakse.

The laboratory tests mentioned here were all carried out at the Enterprise for Survey & Construction Material Laboratory of Laos except for thin-section examinations of rock and alkali-aggregate reaction tests performed in Japan.

2.4.2 Test Results and Considerations

(1) Tests Results

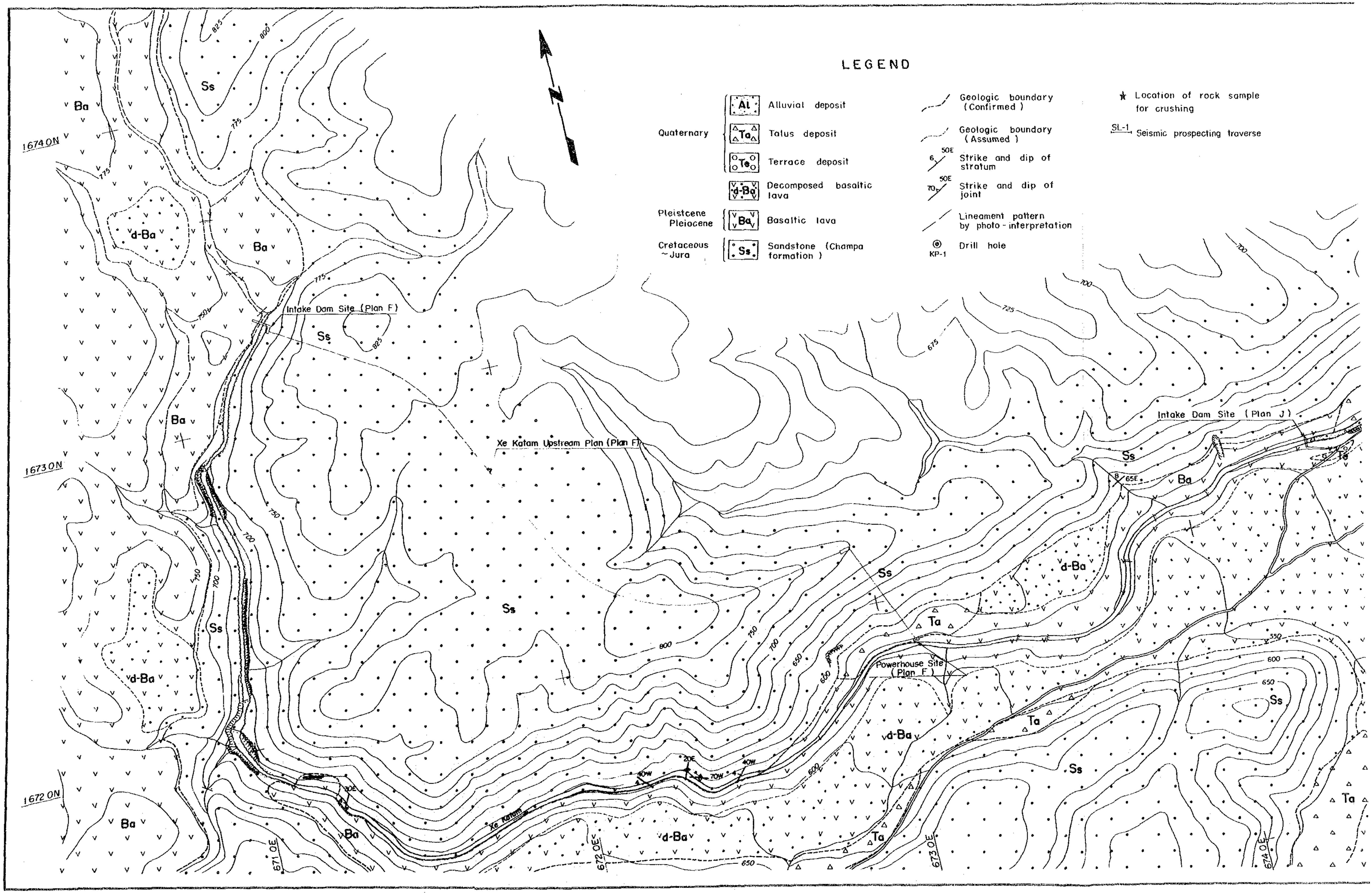
The test results are given in Table III-2-6 and Figs. III-2-7 to III-2-10. To depend on gradation analysis results, the sand (②) sampled from the Mekong River near Pakse is a well-sorted sand made up approximately 70% by particles of 0.3 mm max and 0.6 mm max, but an imbalance can be seen in particle sizes. Except the gradation analysis, another results of specific gravity, abrasion, organic impurities content tests of the sand (②) and river-bed gravel (basalt ①) are good when compared with American standards (ASTM) and Japanese standards (JIS), and it is judged that application of these to concrete aggregates will be appropriate.

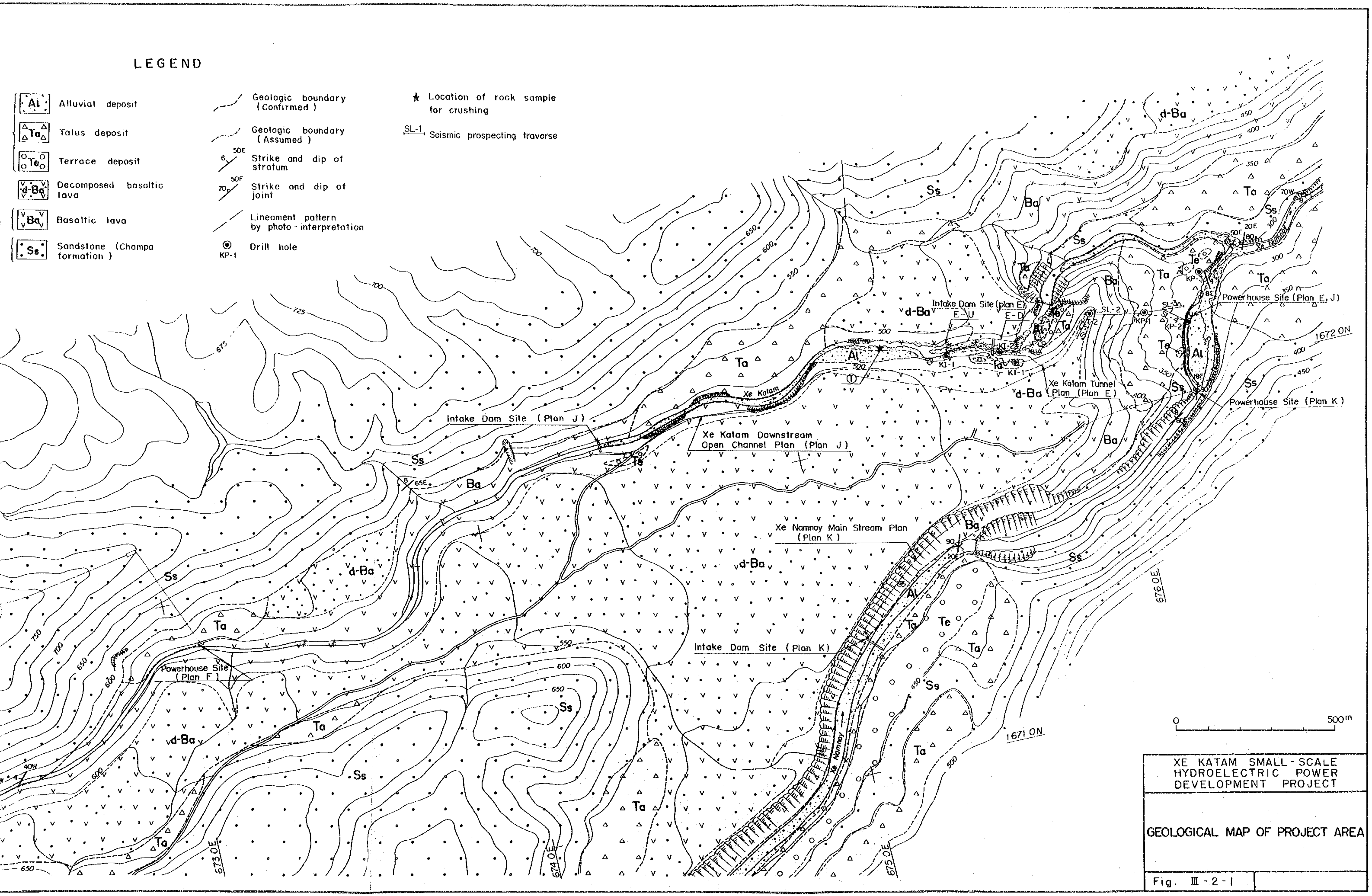
(2) Consideration

As concrete aggregates, there are no deposited materials existing in large quantities in the project area which can be directly used.

Basaltic lava as the basement rock and river-bed gravels consisting mainly of basaltic lava are distributed in this area. The river-bed gravel consisting of basaltic lava is considered to be suitable for application as concrete aggregate according to the results of specific gravity, abrasion, and organic impurities tests, etc. Therefore, it is thought crushing the river-bed gravel or the basement rock basaltic lava to obtain concrete aggregate would be a good method. As for the sand collected from the Mekong River, although there is an imbalance in the graduation, it is thought possible for the sand to be used as fine aggregate for concrete adjusting gradations by blending with crushed basaltic lava.

Further, the river-bed gravels is composed of hard sandstones and basaltic rocks of diameter 20 to 100 cm, is distributed at near the powerhouse site. The deposit area of the river-bed gravels is 50 m wide and 150 m long. Therefore it is thought possible to use the river-bed gravels for concrete aggregate.

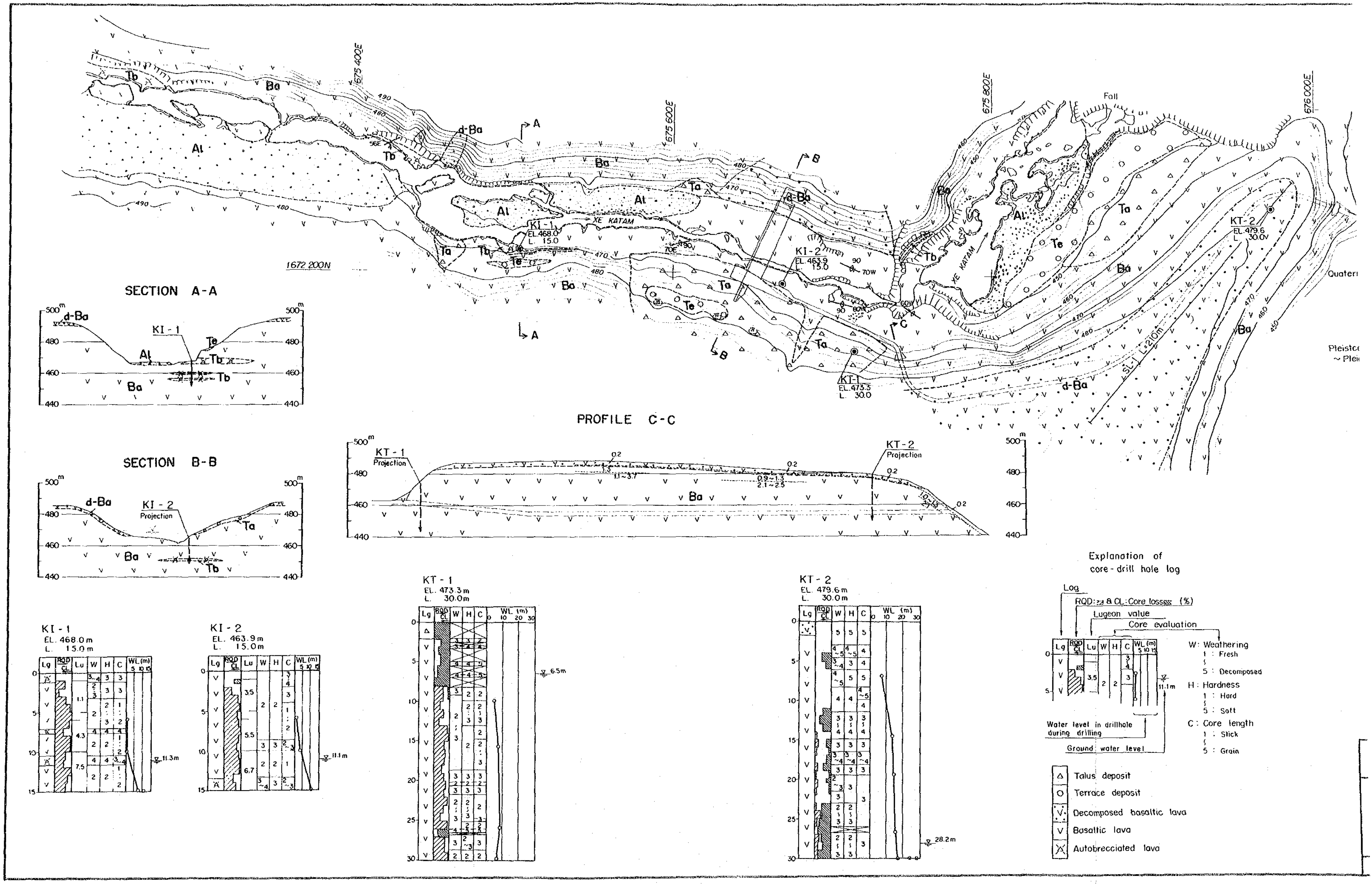

LEGEND
Quaternary
Al Alluvial deposit
Ta Talus deposit
Te Terrace deposit
d-Ba Decomposed basaltic lava
Pleistcene Pleiocene
Ba Basaltic lava
Cretaceous ~Jura
Ss Sandstone (Champa formation)
Geologic boundary (Confirmed)
Geologic boundary (Assumed)
Strike and dip of stratum
Strike and dip of joint
Lineament pattern by photo-interpretation
Drill hole
KP-1
Location of rock sample for crushing
SL-1 Seismic prospecting traverse
N
Intake Dam Site (Plan F)
Xe Katam Upstream Plan (Plan F)
Intake Dam Site (Plan J)
Powerhouse Site (Plan F)
Xe Katam
1674 0N
1673 0N
1672 0N
671 0E
672 0E
673 0E
674 0E



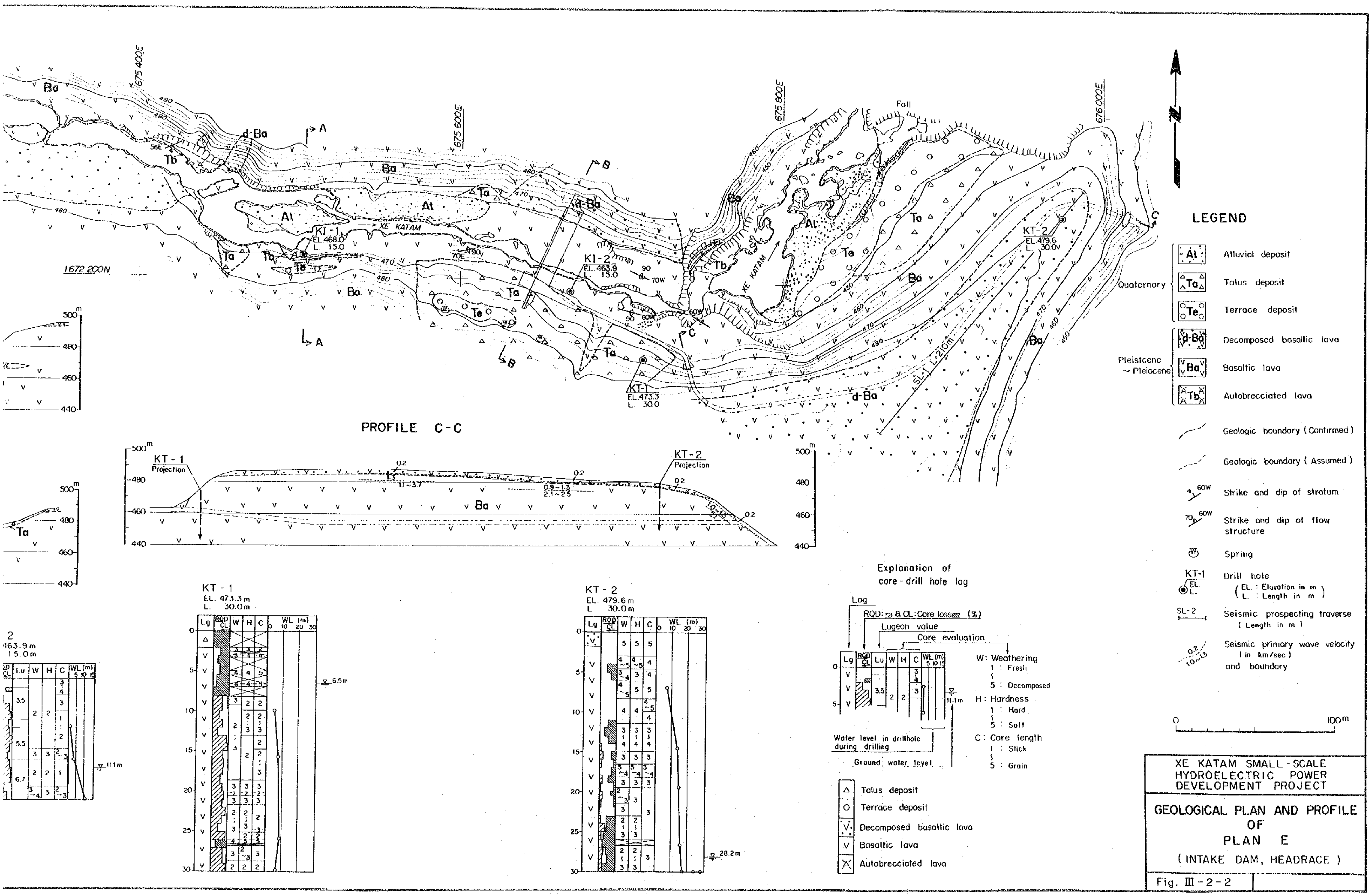
XE KATAM SMALL - SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT

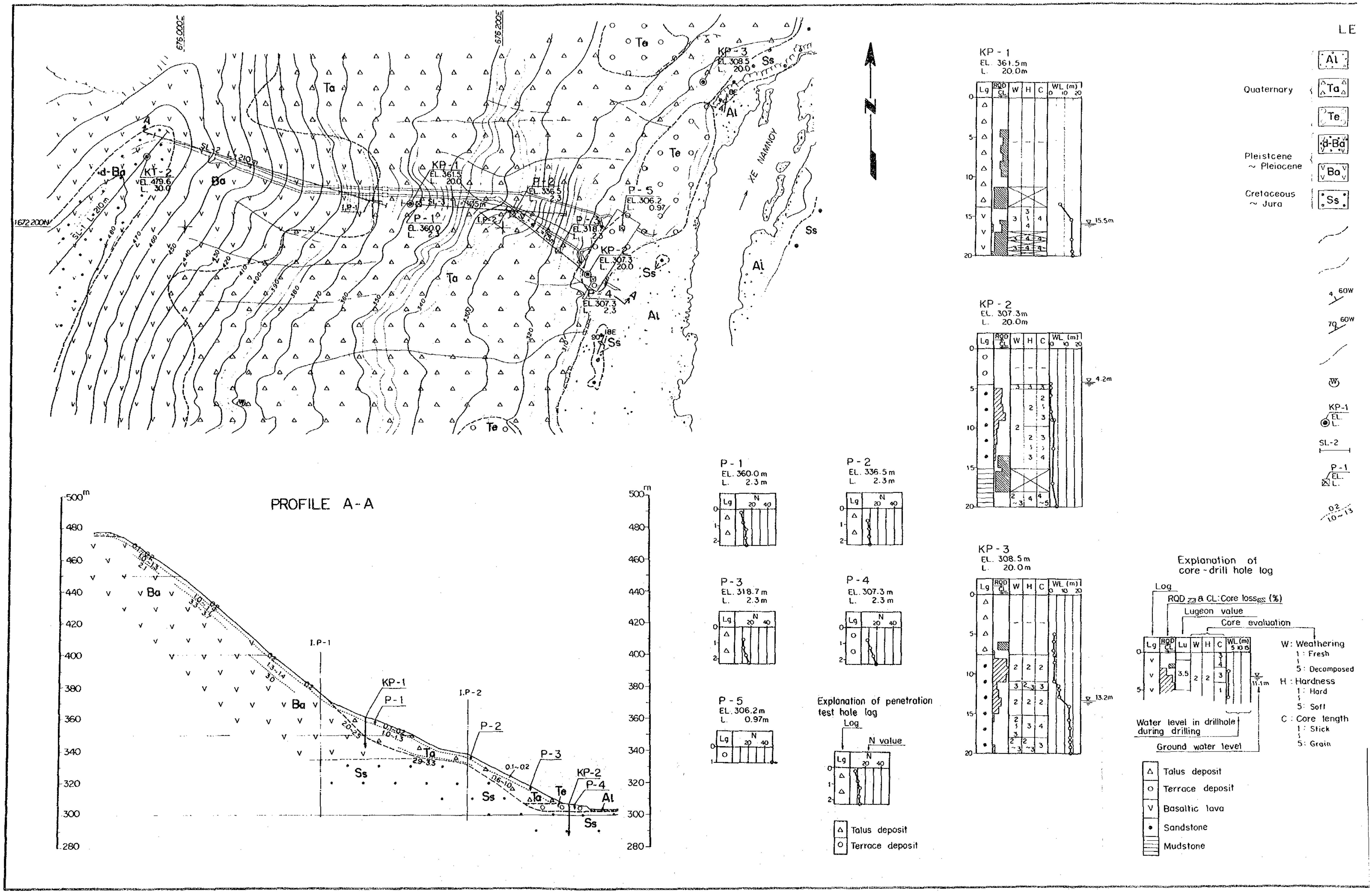
GEOLOGICAL MAP OF PROJECT AREA

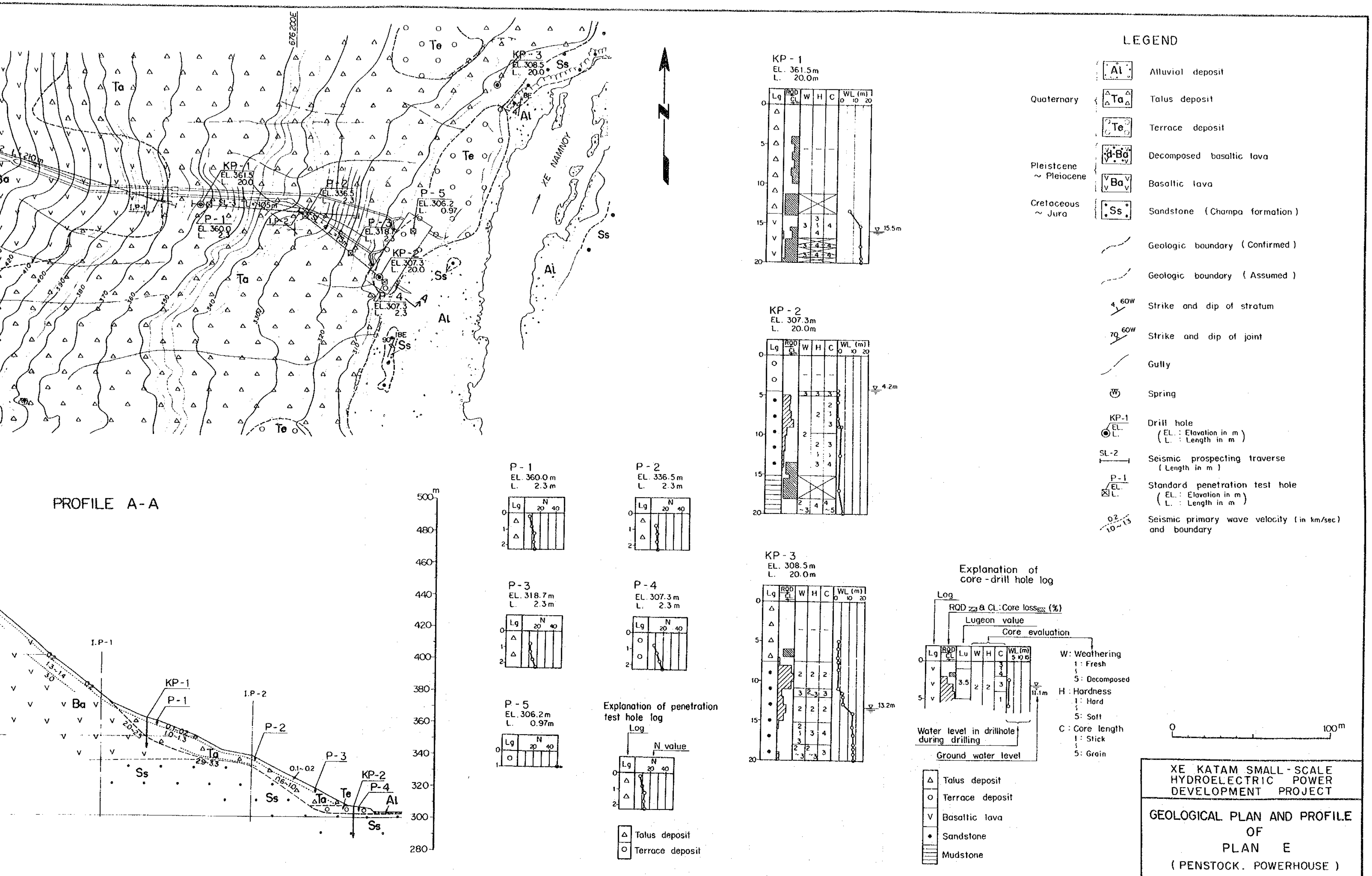
Fig. III - 2 - 1



675 400E
675 600E
675 800E
676 000E
1672 200N
XE KATAM
Fall
SECTION A-A
SECTION B-B
PROFILE C-C
KI-1
EL. 468.0
L. 15.0
KI-2
EL. 463.9
L. 15.0
KT-1
EL. 473.3
L. 30.0
KT-2
EL. 479.6
L. 30.0
Projection
SL. L=210m
Quaterr
Pleistoc
~ Plei
KI - 1
EL. 468.0 m
L. 15.0 m
KI - 2
EL. 463.9 m
L. 15.0 m
KT - 1
EL. 473.3 m
L. 30.0 m
KT - 2
EL. 479.6 m
L. 30.0 m
Lg
RQD CL
Lu
W
H
C
WL (m)
11.3m
11.1m
6.5m
28.2m
Explanation of
core - drill hole log
Log
RQD: & CL: Core losses (%)
Lugeon value
Core evaluation
W: Weathering
1 : Fresh
5 : Decomposed
H: Hardness
1 : Hard
5 : Soft
C: Core length
1 : Stick
5 : Grain
Water level in drillhole during drilling
Ground water level
Talus deposit
Terrace deposit
Decomposed basaltic lava
Basaltic lava
Autobrecciated lava


LEGEND
Quaternary
Al Alluvial deposit
Ta Talus deposit
Te Terrace deposit
Pleistcene ~ Pleiocene
d-Ba Decomposed basaltic lava
Ba Basaltic lava
Tb Autobrecciated lava
Geologic boundary (Confirmed)
Geologic boundary (Assumed)
Strike and dip of stratum
Strike and dip of flow structure
Spring
Drill hole (EL. : Elavation in m; L. : Length in m)
Seismic prospecting traverse (Length in m)
Seismic primary wave velocity (in km/sec) and boundary
0 100m
PROFILE C-C
KT-1 Projection
KT-2 Projection
KT-1
EL. 473.3 m
L. 30.0 m
KT-2
EL. 479.6 m
L. 30.0 m
Explanation of core-drill hole log
Log
RQD & CL: Core loss (%)
Lugeon value
Core evaluation
W: Weathering 1 : Fresh ~ 5 : Decomposed
H: Hardness 1 : Hard ~ 5 : Soft
C: Core length 1 : Stick ~ 5 : Grain
Water level in drillhole during drilling
Ground water level
Talus deposit
Terrace deposit
Decomposed basaltic lava
Basaltic lava
Autobrecciated lava
XE KATAM
Fall
SL-1 L=210m
XE KATAM SMALL-SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT
GEOLOGICAL PLAN AND PROFILE OF PLAN E
(INTAKE DAM, HEADRACE)
Fig. III-2-2

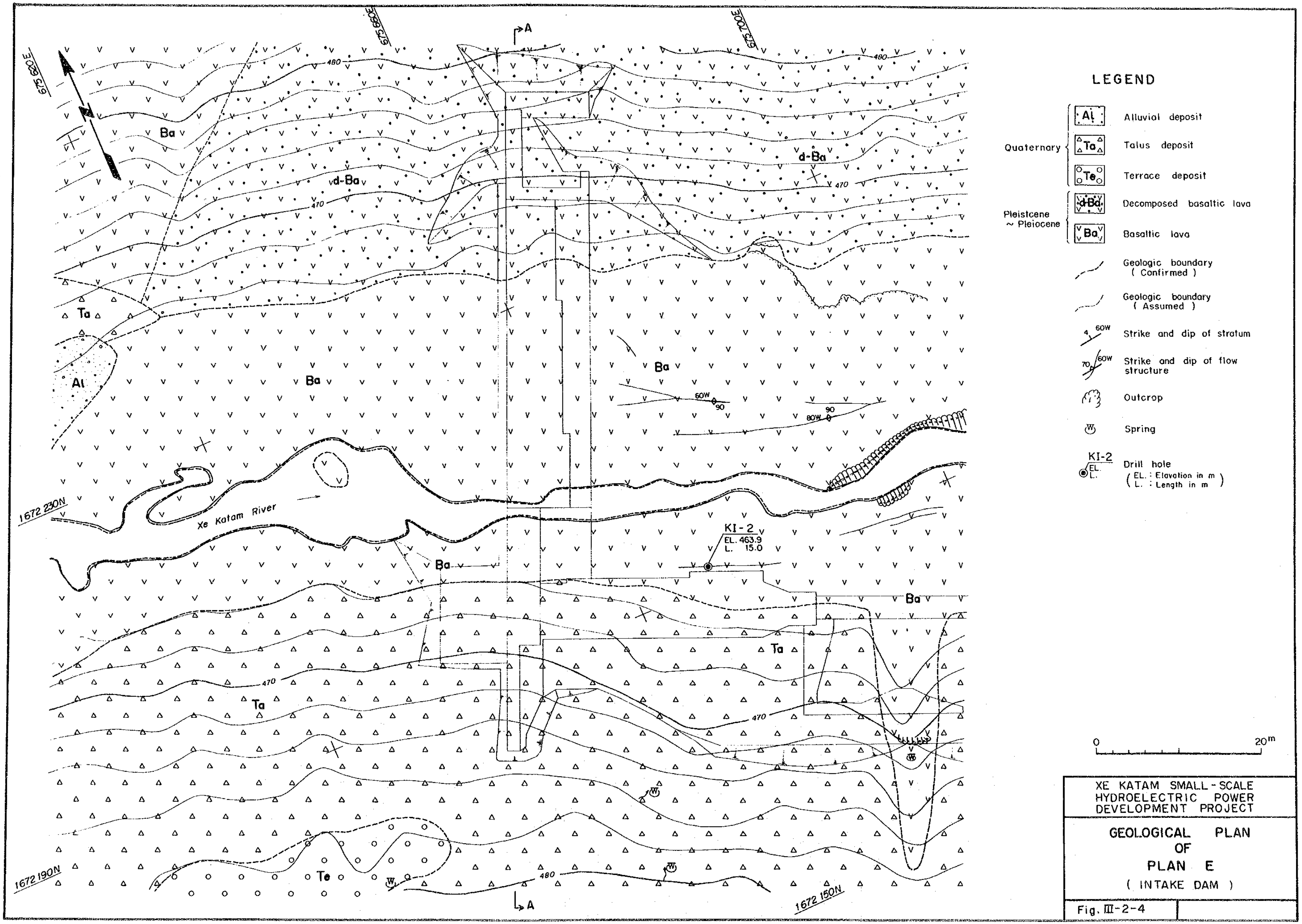

PROFILE A-A
KP-1
EL. 361.5m
L. 20.0m
KP-2
EL. 307.3m
L. 20.0m
KP-3
EL. 308.5m
L. 20.0m
P-1
EL. 360.0m
L. 2.3m
P-2
EL. 336.5m
L. 2.3m
P-3
EL. 318.7m
L. 2.3m
P-4
EL. 307.3m
L. 2.3m
P-5
EL. 306.2m
L. 0.97m
KT-2
EL. 479.6
L. 30.0
XE NAMNOY
Explanation of penetration test hole log
Log
N value
Talus deposit
Terrace deposit
Explanation of core-drill hole log
Log
RQD & CL: Core loss (%)
Lugeon value
Core evaluation
W: Weathering
1: Fresh
5: Decomposed
H: Hardness
1: Hard
5: Soft
C: Core length
1: Stick
5: Grain
Water level in drillhole during drilling
Ground water level
Talus deposit
Terrace deposit
Basaltic lava
Sandstone
Mudstone
Quaternary
Pleistcene ~ Pleiocene
Cretaceous ~ Jura
LE



XE KATAM SMALL-SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL PLAN AND PROFILE OF PLAN E (PENSTOCK. POWERHOUSE)

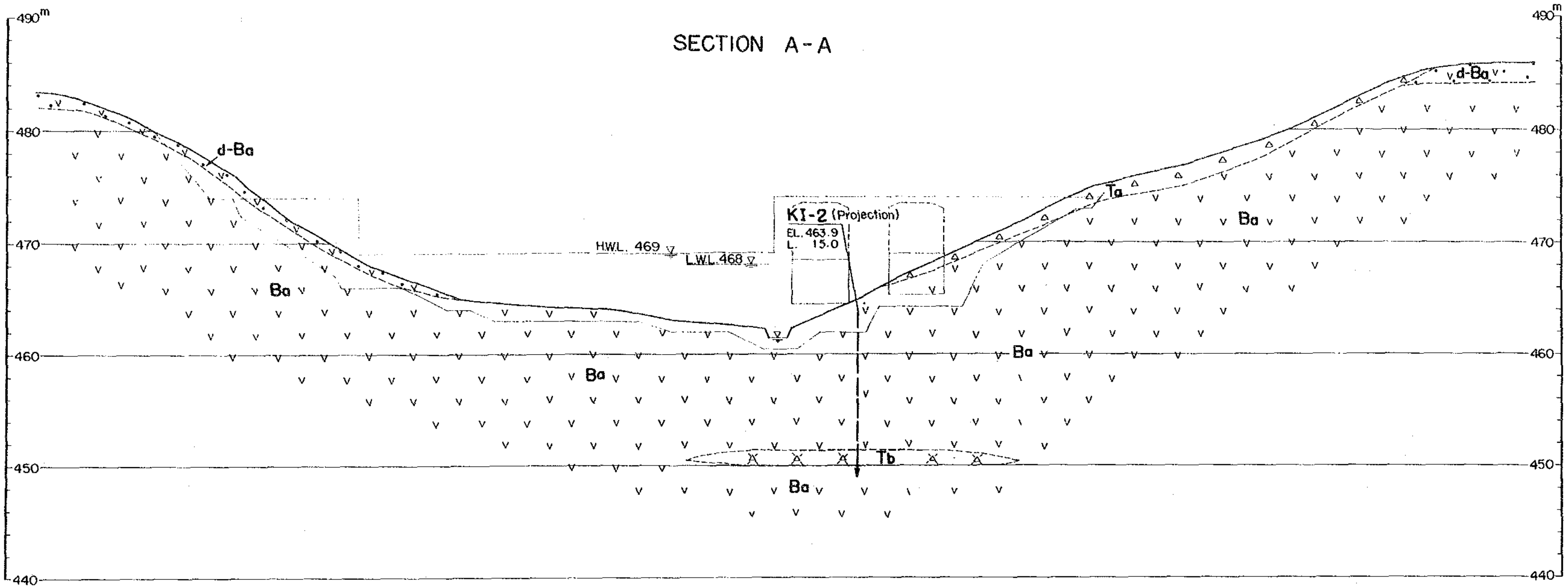
Fig. III-2-3



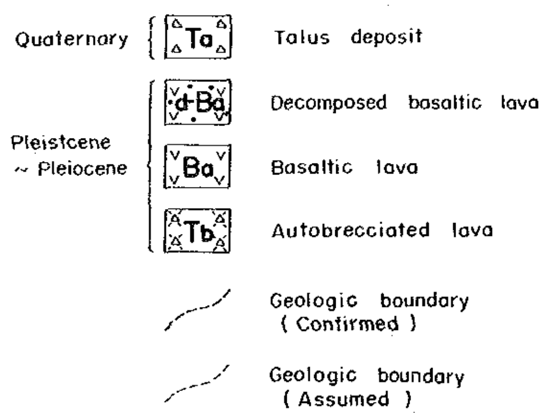
XE KATAM SMALL-SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT

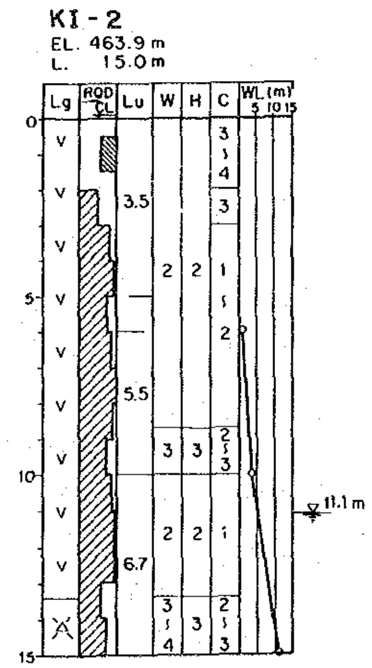
GEOLOGICAL PLAN OF PLAN E (INTAKE DAM)

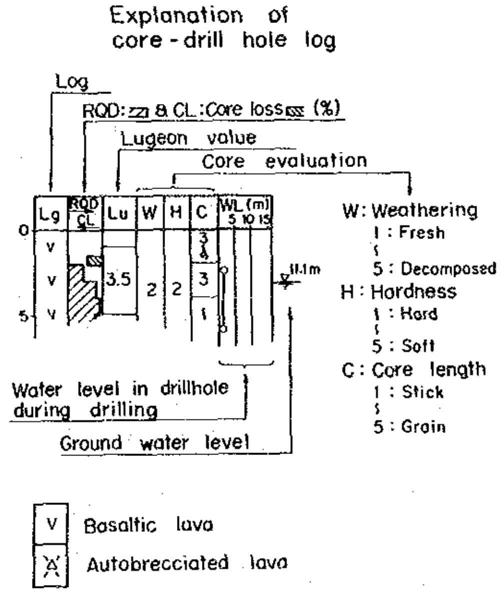
Fig. III-2-4



LEGEND



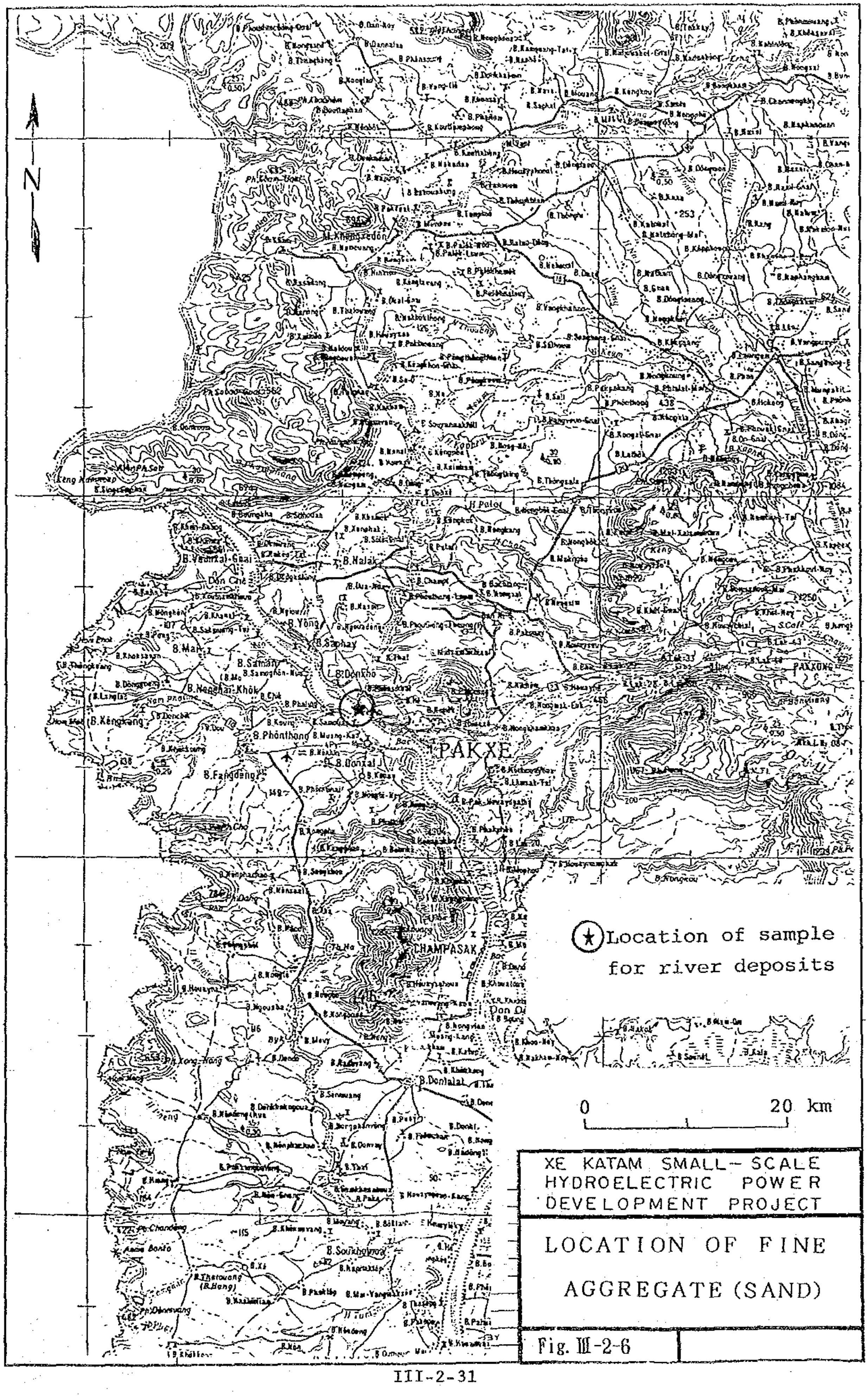




XE KATAM SMALL-SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL SECTION OF PLAN E (INTAKE DAM)

Fig. III-2-5



XE KATAM SMALL-SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT

LOCATION OF FINE AGGREGATE (SAND)

Fig. III-2-6

Table Ⅲ-2-5 Quantity and Items of Laboratory Test for Concrete Aggregate

Sample No	Sampling location	Thin section	Specific gravity	Absorp-tion	Unit weight	Grain-size analysis
① Ba-saltic lava	Lower Xe Katam River	1	1	—	2	2
② Sand	MeKong River(near Pakse)	—	1	1	1	1
	Total	1	2	1	3	3

Sample	Organic impurities	Abration loss	Alkali-aggregate reaction	Flatness and slenderness test
① Ba-saltic Lava	1	1	1	1
② Sand	1	—	—	—
Total	2	1	1	1

Table Ⅲ-2-6 Results of Laboratory Test for Concrete Aggregate

Sample No	Sampling location	Thin section	Specific gravity	Absorpt-ion(%)	Unit weight (kg/l)	Grain-size analysis
① Ba-saltic lava	Lower Xe Katam	Olivine basalt: Olivine plagioclase	2.96	—	1st. stage Loose :1.46 Rodded:1.48 2st. stage Loose :1.50 Rodded:1.68	Show in Fig. Ⅲ-2-7 ~ Fig. Ⅲ-2-8
② Sand	Mekong River(near Pakse)	—	2.55	1.41	Loose :1.40 Rodded:1.52	Show in Fig. Ⅲ-2-9

Sample	Organic impurities	Abration loss (%)	Alkali-aggregate reaction	Flatness and slenderness test
① Ba-saltic lava	Organic Plate No 1	19.30	Show in Fig. Ⅲ-2-10	Flatness=1.28 ~1.57 slenderness=0.54~ 0.74
② Sand	Organic Plate No 2	—	—	—

Fig. III-2-7
Grain-size Analysis (No①: 1st Stage Crushing)

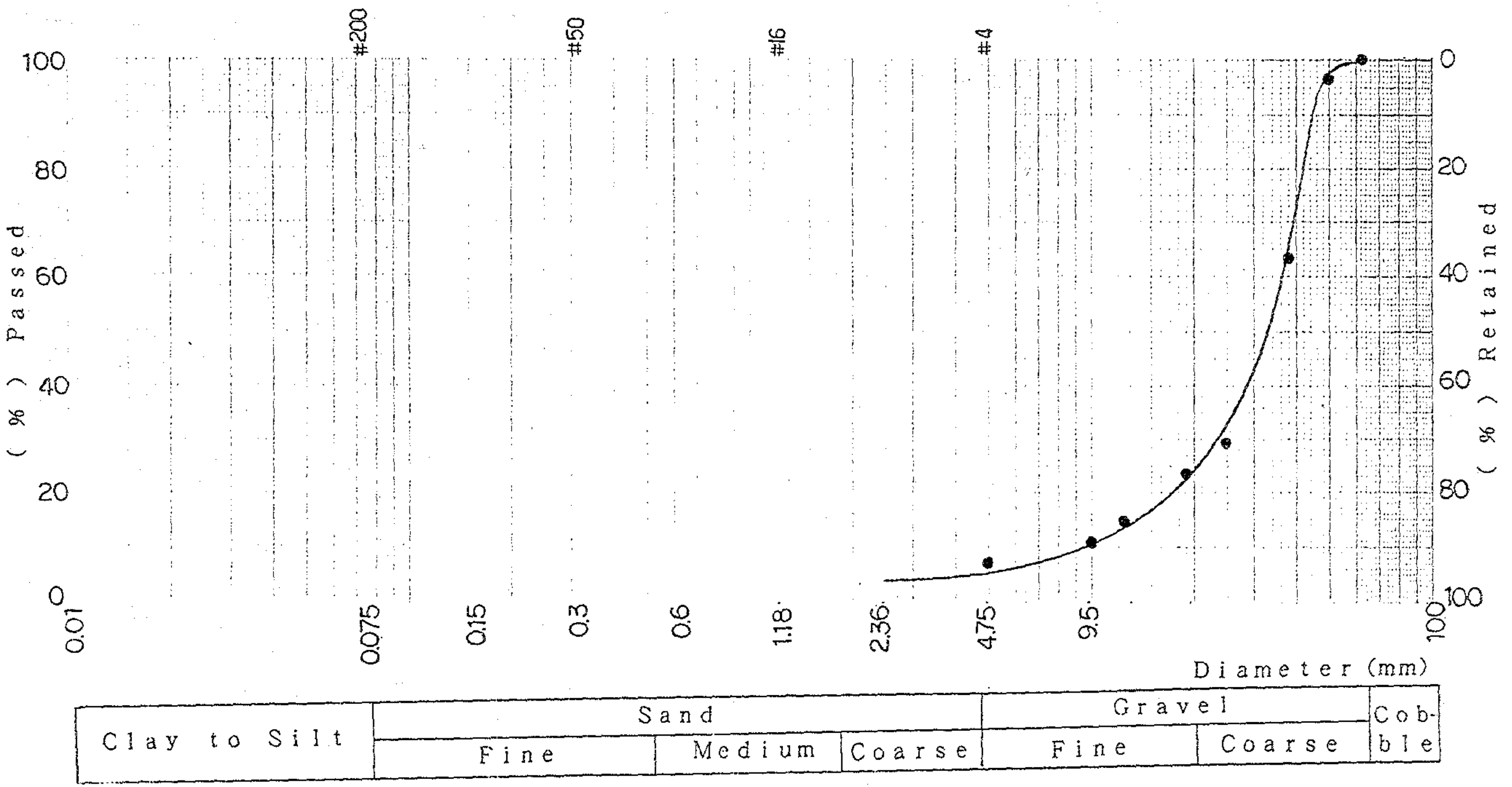


Fig. III-2-8
Grain-size Analysis (No①: 2st Stage Crushing)

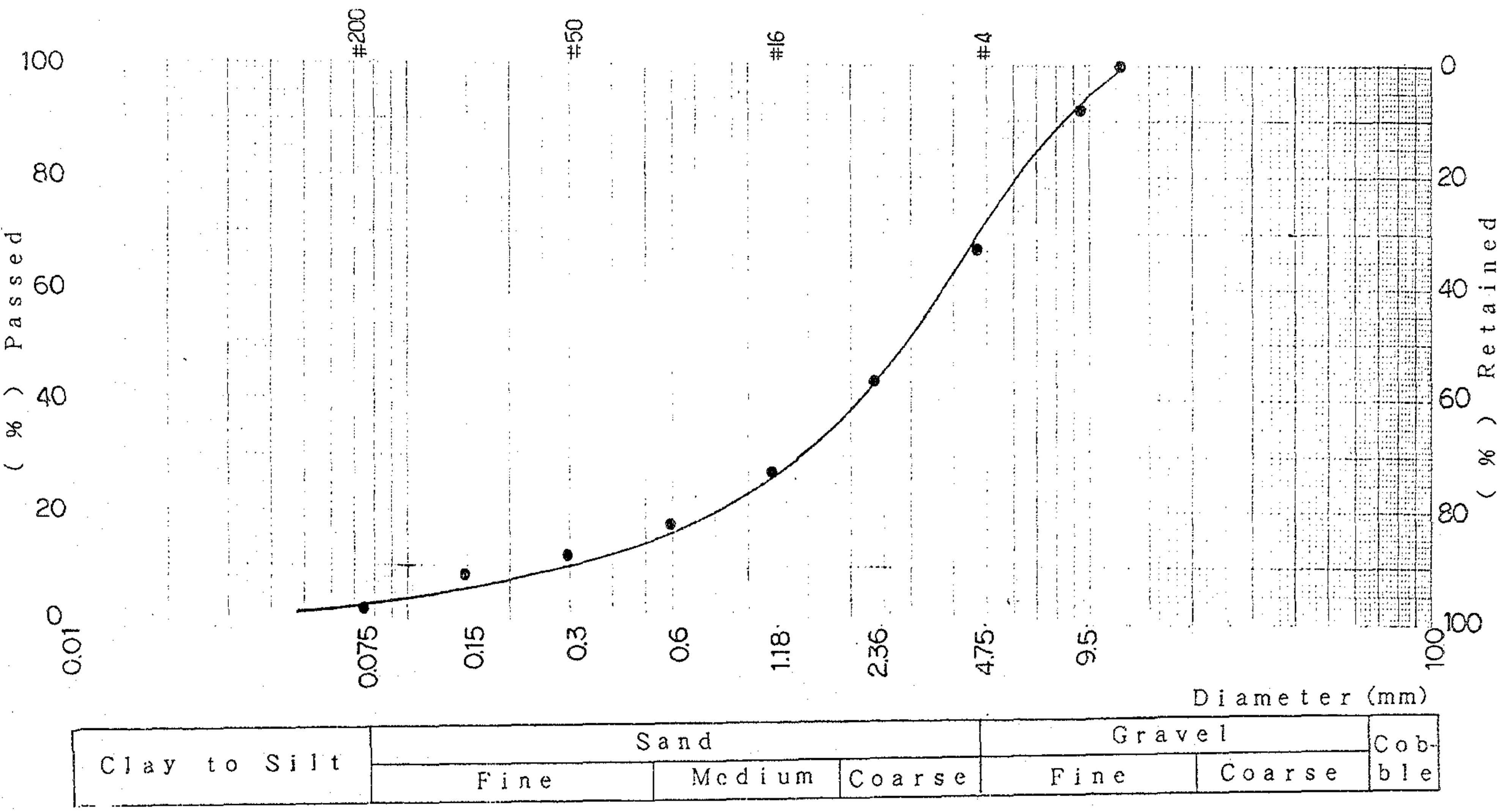
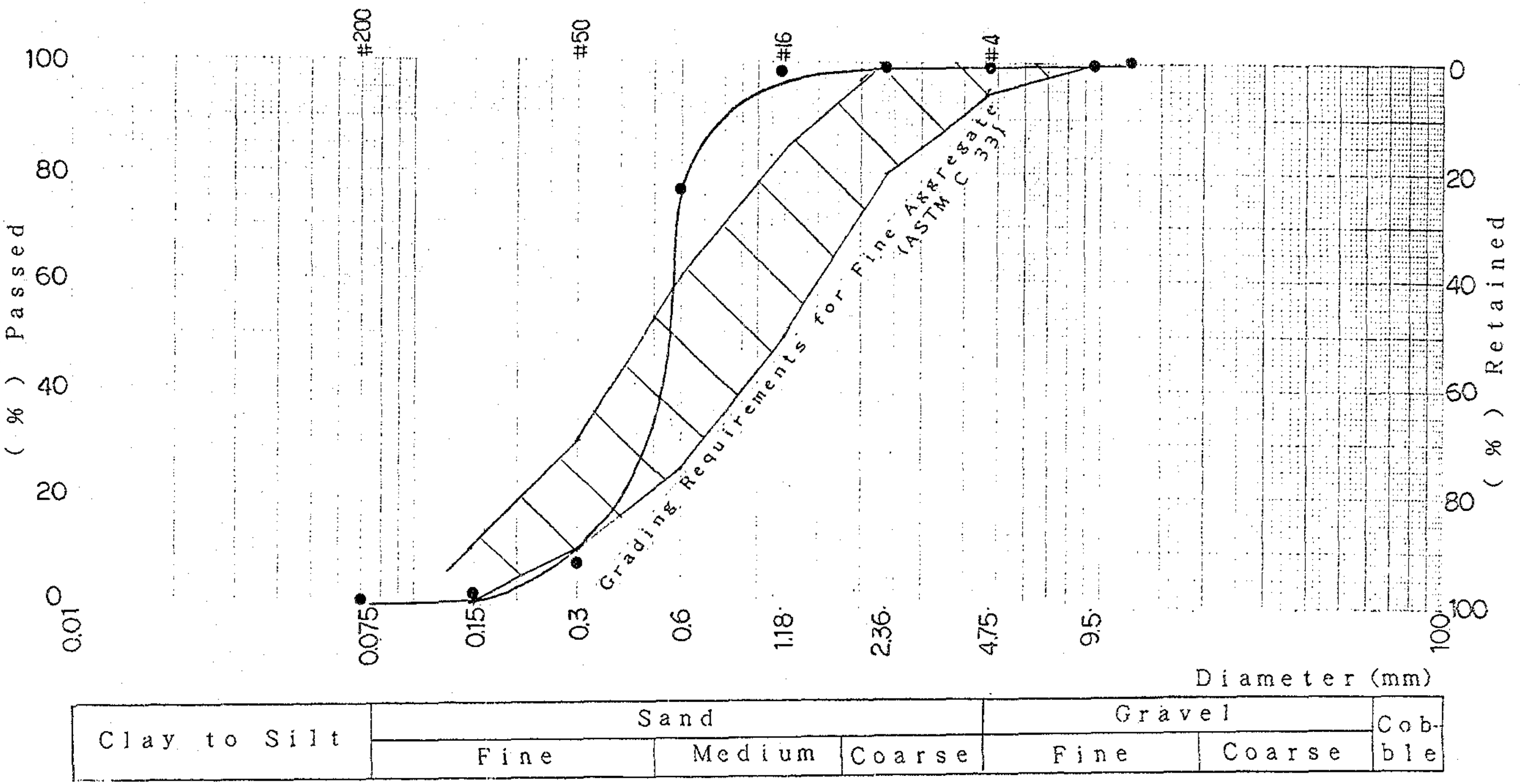


Fig. III-2-9
Grain-size Analysis (No②)



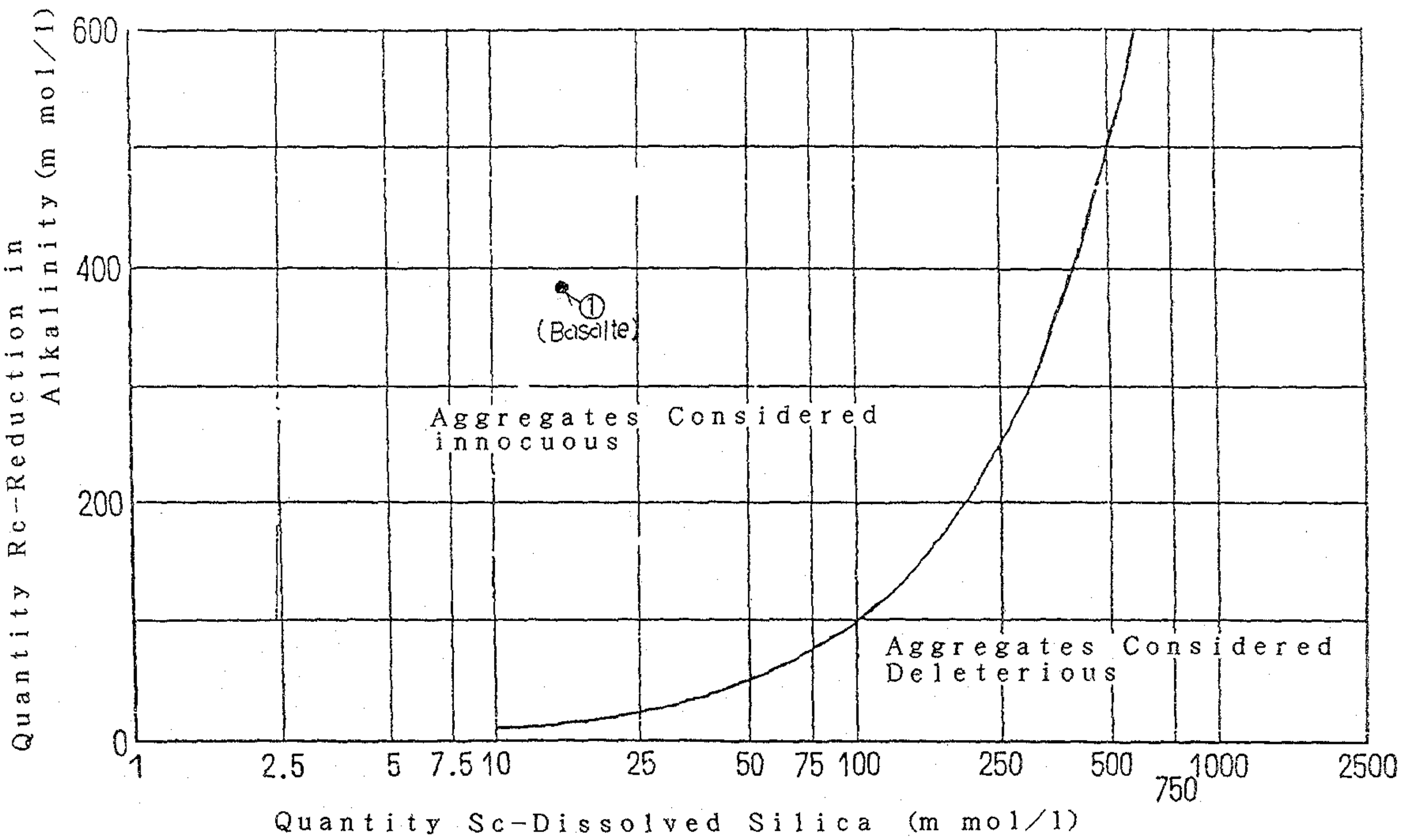


Fig. III-2-10 Result of Reduction in Alkalinity Test

2.5 Seismicity

The geological structure of the project area, the seismicity, and evaluation of the design seismic coefficient to be used in earthquake-resistant design will be discussed in this section.

2.5.1 Geological Structure of Lao PDR.

(1) Metamorphic rocks of the early Paleozoic Era are the oldest in the Indochinese Peninsula, and the skeleton of the geological structure was formed by the three orogenic movements shown in Fig. III-2-11 which occurred around these rocks. The first was the Hercynian Orogeny which was active in the Carboniferous Period. The project area belongs to a land zone formed by this Hercynian Orogeny and at present old rocks formed at that time can be seen in the Annam Mountain Range to the east of the project area. Around the land zone formed by the Hercynian Orogeny there is the land zone made by the Indochinese Orogeny which was active mainly in the Triassic Period of the Mesozoic Era, while further, there is the land zone around it formed after by the Himalayan Orogeny active from the Cretaceous Period of the Mesozoic Era to the Quaternary Period.

After the Indochinese Orogeny, the western region of Laos along the Mekong River including the project area was covered at one time by neretic deposits, and subsequently, it has been a stable region where there has been no prominent folding or metamorphism, while neither is there any active volcano.

(2) Active Structure

Meanwhile, seen from the point of view of plate tectonics theory, the Indochinese Peninsula belongs to the Eurasian Plate shown in fig. III-2-12 which is bordered on the western and southern sides by the Indian Plate and on the eastern side by the Philippines Sea Plate. The project site is located at roughly the center of Indochinese Peninsula belonged the Eurasian Plate and is more than 1,000 km distant from the

Indian Plate and the Philippines Sea Plate. In general, a seismically active zone is often situated near the boundary between plates, and from the standpoint of plate tectonics theory, it may be considered that the project area is a zone where there are few earthquakes.

2.5.2 Seismicity

The distribution of earthquakes of magnitude (M) 4 or higher which occurred throughout the world from 1964 to 1982 is shown in Fig. III-2-13. The distribution of earthquakes occurring from 1981 to 1988 within a radius of 1,000 km with the project site as the center is shown in fig. III-2-14.

It may be judged from Figs. III-2-13 and III-2-14 that the project area is a zone of low seismicity.

2.5.3 Estimate of Earthquake Risk and Design Seismic Coefficient

(1) Estimate of Maximum Acceleration at Project Site

To determine the design seismic coefficient, prediction s and evaluations of the maximum acceleration at the ground surface in the project area were made. The earthquake data used for the predictions and evaluations were all of earthquakes M6 or higher within a radius of 1,000 km from the project area indicated in fig. III-2-14, and all earthquakes within a radius of 500 km. The earthquakes listed up are given in Table III-2-7.

The attenuation models used in prediction and evaluation of earthquakes were the two below from among those already proposed.

The "A" in the equations is maximum acceleration (gal), "M" magnitude of earthquake, and "R" hypocentral distance (km).

$$\text{Log } A = 2.674 + 0.278\,M - 1.301\,\text{Log }(R + 25) \quad \cdots\cdots\cdots\cdots \quad [1]$$

proposed by R. K. Mcguire

$$\text{Log } A = 2.041 + 0.347 M - 1.6 \text{ Log } R \quad \cdots\cdots \quad [2]$$

proposed by L. Esteve and E. Rosenblueth

Eq. [1] was proposed based on earthquake data recorded at the ground surface from soft ground to hard rock.

Eq. [2] is an equation for on top of hard ground modified for on top of bedrock.

The results of calculations by the abovementioned two attenuation models are given in Table III-2-7. According to the calculation results in Table III-2-7, the maximum acceleration at the ground surface estimated for the project area is 9.46 gal at most.

(2) Earthquake Risk Evaluation by Stochastic Theory Technique

The maximum acceleration for any return period can be obtained applying third type asymptotic distribution based on Gumbel's extremal statistics theory. The contour lines for predictions of maximum acceleration of 200-year return period are shown in Fig. III-2-15.

The earthquake data used here were the data from 1901 to 1977 on earthquakes with hypocenters in a range of 85 to 125° east longitude and 5° south latitude to 35° north latitude, which includes the entire Indochinese Peninsula furnished by NOAA (National Oceanic and Atmospheric Administration).

It can be comprehended from fig. III-2-15 that the project area belongs to a zone of maximum acceleration of 20 gal for a return period of 200 years.

(3) Design Seismic Coefficient

Although there is no established theory at the moment regarding the relationship between maximum acceleration of earthquake motion and design seismic coefficient, the equation below is often used as a method of transforming maximum acceleration of earthquake motion into design seismic coefficient:

$$\alpha_{eff} = R \times A_{max}/980$$

Where, α_{eff}: effective design seismic coefficient

R: reduction factor (values of about 0.5 to 0.65 used in past studies)

As a result of earthquake risk evaluation based on historical earthquakes, the maximum acceleration of earthquake motion for this project site was estimated to be 20 gal at most.

The design seismic coefficient estimated from this results will be:

$$\alpha_{eff} = (0.5 \text{ to } 0.65) \times 20/980 \fallingdotseq 0.02$$

— Earth science vol.16 (1979) —

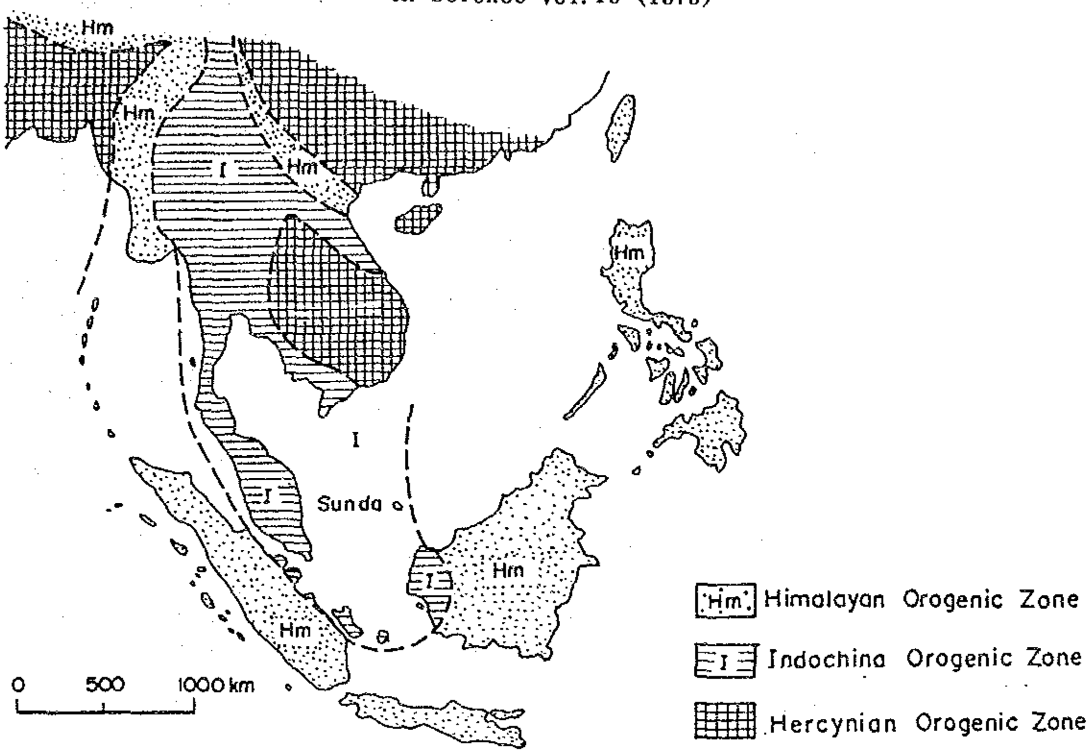


Fig. Ⅲ-2-11 General Geological Structure of Southeast Asia

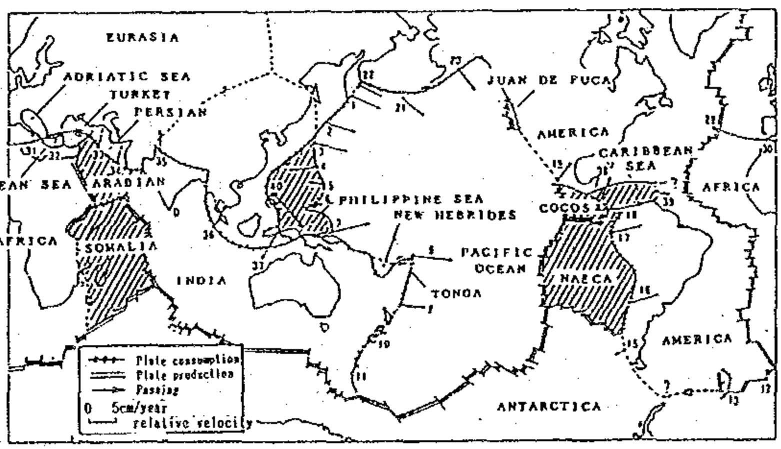


Fig. Ⅲ-2-12 Distribution of Major Tectonic Plates on the Earth and Plate Boundaries

— Chronological table of science (1988)—

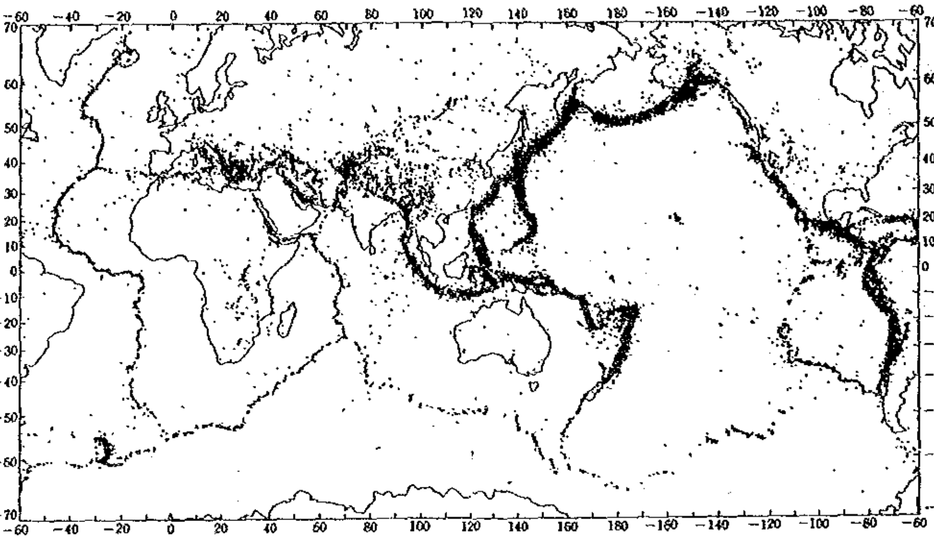


Fig. III-2-13 Epicenters of Earthquakes of Magnitude : M ≥ 4 and Focal Depth : H ≦ 100 km which Occurred during the Period from 1964 to 1982 in the World

— Lower mekong hydrologic yearbook (1981-1988)—

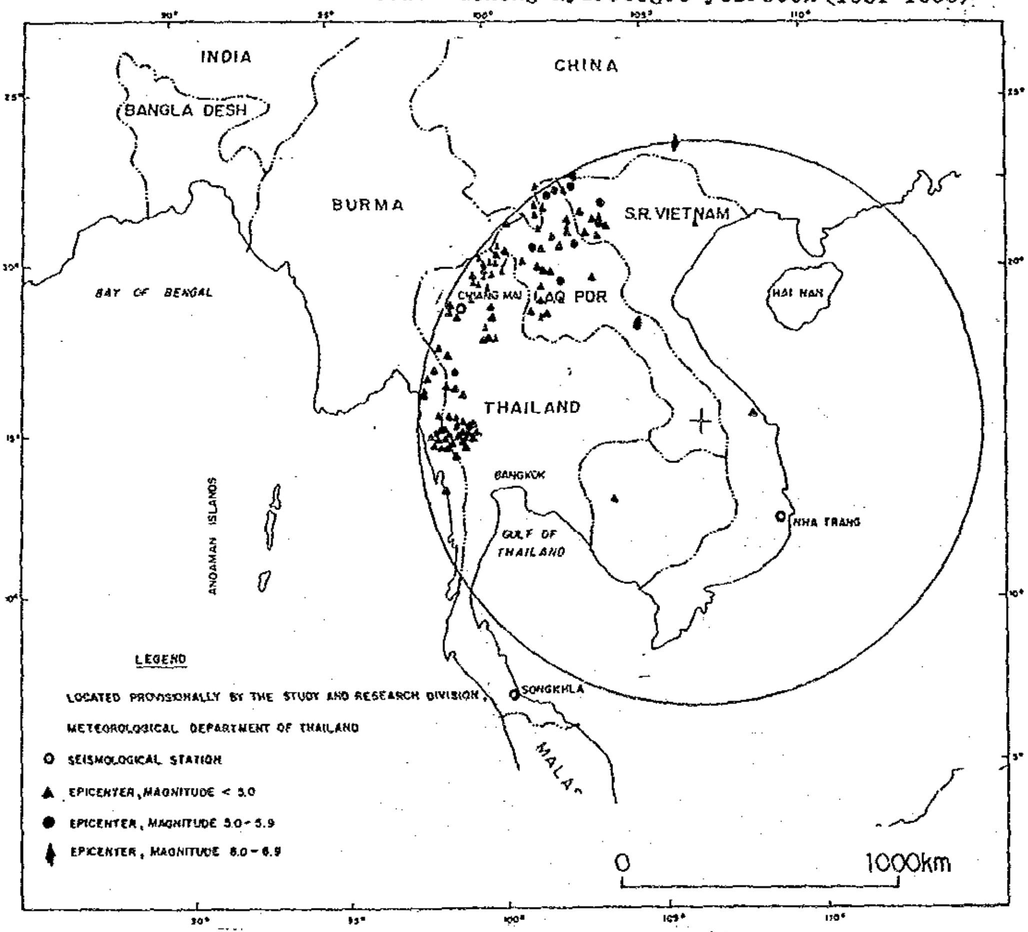


Fig. III-2-14 Seismicity Around the Project Site during 1981 - 1988, and < 1,000 km

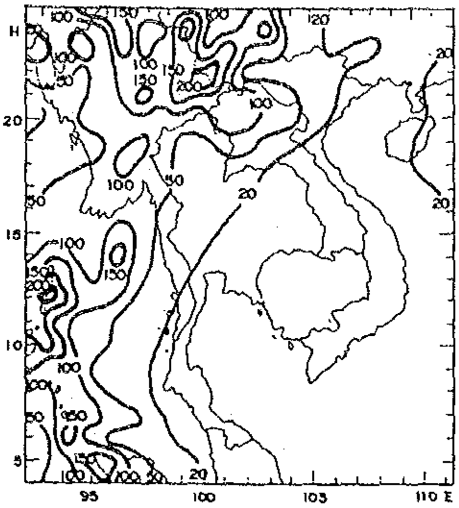


Fig. III-2-15 Seismic Risk Map in and around Thailand
Amax for Return Period Tr = 200 Years.

—EPDC (1989) to be arrenged
NOAA data(1901-1987)—

Table III-2-7 Representative Earthquakes in the Vicinity of the Project Site

Date	Epicenter	Magnitude	Location and distance from site	Estimates of Maximum Acceleration at the Site(gal)	
				Equation ① (Mcguire)	Equation ② (Esteva and Rosenblueth)
1982 2.18	18.3N 104.7E	4.5	Lao PDR 440km	2.85	0.24
1982 10.27	23.5N 106.0E	6.2	China 1000km	3.02	0.25
1983 12.15	13.0N 103.8E	4.6	Kampuchea 400km	3.41	0.30
1984 3.22	15.5N 108.2E	4.9	Viet Nam 200km	9.46	1.15
1985 10.18	18.1N 104.7E	5.3	Lao PDR 400km	5.35	0.52

2.6 Conclusion

In this Section 2, the results of summarizations regarding geological engineering conditions and concrete aggregates, and earthquakes in connection with the Xe Katam Tunnel Plan (E) are described in outline below.

2.6.1 Xe Katam Tunnel Plan (E)

- The two alternatives of an upstream plan (E-U) and a downstream plan (E-D) have been examined for the intake dam of this plan, and the basement rocks distributed are fresh and hard basaltic lava and autobrecciated lava. Exploratory boring consisting of one drillhole, 15 m each, has been carried out at these project sites to grasp the properties and permeabilities of the basaltic lava and autobrecciated lava.

  According to surface geological investigations and exploratory boring, autobrecciated lava of thickness about 1 m is interbedded in the basement rock basaltic lava in both the upstream plan (E-D) and the downstream plan (E-D). The Lugeon values of the basaltic lava and the autobrecciated lava are from 1.1 to 7.5, with permeability being slightly high at the lower parts. Water levels in the drillholes are 0.3 to 3.4 m in drilling to approximately 10 m, and approximately 11 m in drilling to 15 m depth, with the groundwater table dropping at deeper parts.

  As described above, the basement rocks at the individual intake dam sites are thought to pose no problem concerning bearing power for intake dams several meters in height. However, when looking at the relationship between depth of drillhole and the water level in the hole, there is a zone of high permeability at deeper than 10 m (the distribution of autobrecciated lava is thought to be the main cause) and it is thought necessary for a detailed investigation to be made hereafter concerning permeability.

- The headrace tunnel would have a total length of approximately 340 m and maximum cover of approximately 30 m, and the entire route will pass through basaltic lava. According to exploratory boring performed near the end of the headrace tunnel, weathering of basaltic lava has progressed to a depth of about 23 m, and it is estimated that the headrace tunnel will pass under through this weathered basaltic lava. However, thorough care needs to be exercised in excavation of the headrace tunnel.

- At the slope of approximately 130 m length of the upper part of the penstock route there is distribution of weathered basaltic rock, while below this, at the slope of approximately 140 m length, there is distribution of talus deposits. Boring and standard penetration tests were carried out at the penstock route to investigate the thickness and N-value of the talus deposits. Also, seismic prospecting was done to estimate the elastic wave velocities and thicknesses of the basaltic lava and talus deposits.

  The elastic wave velocity (V_p) of the basaltic lava was 1 km/sec at around a depth of 2 m, while the V_p of the talus deposits was 0.7 km/sec at around a depth of 1.6 m. Judged from the results of boring and seismic prospecting, it is estimated that the thickness of the talus deposits is from 6 to 14 m. the average N-value of these talus deposits is 11.

  As described above, weathered basaltic lava is distributed at the surface layer of the slope at the upper 130 m length of the penstock route, but it is estimated that by performing some amount of excavation of the ground, comparatively fresh bedrock will appear. On the other hand, since is estimated that talus deposits of N-value about 11 are distributed in a thickness of 6 m even where thin at the lower slope of penstock route, it is necessary for these geological conditions to be reflected in design.

- Terrace deposits are widely distributed at the powerhouse site. According to the results of surface reconnaissances and boring, the thicknesses of terrace deposits were from 3.5 to about 5 m, and N-values were from 8 to 50. Hard Sandstone is distributed under the terrace deposits and it is desirable for the powerhouse to contact this sandstone.

2.6.2 Concrete Aggregates

According to the results of surface reconnaissances, large amount of natural aggregates which can be used for concrete without modification are not to be seen in this project area. Therefore, basaltic lava distributed as the basement rock of the project area, river gravel consisting mainly of basaltic lava, and sand of the Mekong River in the vicinity of Pakse were collected and tested to see if they would be applicable as aggregates.

The results of specific gravity and abrasion tests of basaltic lava and sand were good other than for the fact that there was eccentricity in the gradation of sand. With regard to the sand, by adjusting gradation with crushed basaltic lava, it is judged to be usable similarly to the basaltic lava.

2.6.3 Seismicity

The project area is in a land mass which is geologically stable, and is actually an area where few earthquakes have occurred.

As the design horizontal seismic coefficient, earthquake data which would have the greatest effect on the project area were adopted from among various earthquake data and evaluated. As a result, it is estimated to be adequate to evaluate design horizontal seismic coefficient to be about 0.02.

3. Meteorology and Hydrology

Chapter III 3. Meteorology and Hydrology

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3. Meteorology and Hydrology

3.1 Outlines of Meteorology and Hydrology of Xe Katam River Basin

3.1.1 Outline of Basin

The Xe Katam River is one of the major tributaries of the Xe Namnoy River, and its river basin takes up the northwestern part of the Xe Namnoy River Basin spreading out at the southeastern part of the Bolaven Plateau. The fountainhead of the Xe Katam River rises at the central part of the Bolaven Plateau, and the river flows southeast up to merging with the Xe Namnoy at the eastern fringe of the plateau.

The catchment area of the Xe Katam River is approximately 300 km^2, and the area from the upstream to midstream basin except its northern part forms a comparatively flat topography continuing from the central part of the Bolaven Plateau. Vegetation of this flat area consist of cultivated fields of coffee and upland rice, and grasslands or shrubbery, so that there are few parts which comprise bare land. The topsoil of this region is fine-grained soil which has become lateritized, but the thickness of it is thought to be comparatively small. In contrast, the northern part of the middle-upper basin and the lower basin present mountain topographies, and other than some parts where slash-and-burn agriculture is carried out, they are covered by virgin forests of deciduous trees.

The boundary of the Xe Katam River basin is shown in Fig. III-3-1, and the relationship between elevation and area of the basin is shown in Fig. III-3-2.

The basic particulars of the Xe Katam River at the projected Xe Katam intake dam site are as shown below.

- Catchment area	290 km^2
- River length	52 km
- Average basin elevation	1,050 m

3.1.2 Precipitation in Basin

As mentioned in Section 1.3 of Chapter II, there were no existing rainfall observation stations in the Xe Katam River Basin except two automatic rainfall recorders which were installed after the start of this feasibility study. The results of comparisons among the data obtained at these observation stations during a period of a half-year and the observed data at neighboring sites during the same period are given in Table III-3-1. According to the observation results, some trends of rainfall are recognized for the Xe Katam River Basin as below.

i) Average rainfall becomes smaller the more from the west part to the east part of the basin.

ii) Although the correlation of monthly rainfall between the two sites is comparatively good, there is a time lag between rainfall peaks so that the extent of area where has rainfall at the same time seems to be comparatively limited. Accordingly, it can be said that there is little possibility of high intensity rainfall simultaneously throughout the entire basin (see daily rainfall records in Appendix-3).

According to the isohyetal maps contained in the "Lower Meking Hydrologic Yearbook" by the Mekong Committee, the rainfall distribution in and around the Bolaven Plateau has a trend that the amount of rainfall decreases more the more from the central part of the plateau as a peak to the fringes. The trend of i) described above is in agreement with this trend.

With regard to the amount of annual rainfall, although long-term observation data are not available in the Xe Katam River Basin, a average rainfall is found to be approximately 2,800 mm during the 11-year period from 1980 to 1990 at Nonghin located at the west of the Xe Katam River Basin. Judging from the trend of rainfall distribution on the Bolaven Plateau, it seems that the average annual rainfall in the Xe Katam River Basin will be a quantity lower than the above amount of 2,800 mm. Applying the extremely limited information such as data observed in 1991 shown in Table III-3-1, annual rainfall amount in the Xe Katam River Basin is estimated to be approximately 2,100 mm.

Regarding seasonal variation in rainfall, so far as seen in the data observed in 1991, although there is a quantity-wise difference, in the rainfall amounts, it may be thought that the trend of rainfall in the Xe Katam River Basin is more or less the same as that of rainfall at Nonghin.

3.1.3 River Discharge

As mentioned in Section 1.3 of Chapter II, a runoff characteristic originated from topographical and geological influences in the basins is found in the stream flows on the Bolaven Plateau, that is, discharge into streams shows a tendency to be small compared with the large amounts of rainfall. In this connection, the results of study on the runoff data in 1985 and 1986 (shown in Table III-3-2) of the Xe Set River having its basin in the northern part of the Bolaven Plateau are described below.

The basin of the Xe Set River is adjacent to the basin of the Xe Katam River at the central part of the Bolaven Plateau. According to "Lower Mekong Hydrologic Yearbook, 1985-1986, Volume II," rainfall in the Xe Set River Basin is estimated to be around 2,900 mm annually as the average of 1985 and 1986. In contrast,as shown in Table III-3-2, the total annual discharge of the Xe Set River during the same period was approximately 1,350 mm, and the average runoff coefficient during the year is calculated at about 50%. Since the basin of the Xe Katam River has roughly the same topographical characteristic as the Xe Set River Basin, it is imagined that the runoff coefficient of the Xe Katam River Basin is similarly around 50%.

The river discharges in this area differ greatly between rainy and dry seasons following the seasonal variations in rainfall due to monsoons. According to Table III-3-2, at the Xe Set River, the discharge during the half-year from May to October corresponding to the rainy season makes up 79% of the annual discharge. On the other hand, the discharge in March, the month of lowest water, is only 9% of the discharge in August, the month of highest water. And, as mentioned previously, in the minor rainy season of March, there is a amount of rainfall, and although there is a temporary increase in discharge when it rains, this is not as much as a amount to increase the base flow. Because of this, the minimum discharge of the year occurs in the period from the end of March to the latter half of April when the rainy season starts in earnest.

With regard to the Xe Katam River, it is not possible to conclude what the characteristics of discharge are since sufficient runoff data are not available. However, roughly the same trends as at the Xe Set River are seen in the discharge estimated based on the results of investigations performed in 1991 for Ban Nonghin site on the Xe Katam River. (see 3.3.2 and Table III-3-6)

3.1.4 General Meteorology

(1) Air Temperature

The observation data of Nikhon34 meteorological station (EL. 1,150 m) adjacent to the upstream basin of the Xe Katam River, and of Pakse meteorological station (EL. 150 m) located at the western side from the Bolaven Plateau are shown in Table III-3-3.

Because the upstream basin of the Xe Katam River is located at the central part of the Bolaven Plateau where the elevation is high, the air temperature is fairly low compared with the low elevation areas at the outskirts of the plateau. Even in the period from April to May when temperatures become highest, the daily mean temperature is around 26°C and the maximum is about 29°C. On the other hand, from December to January, when temperatures become lowest, the daily mean temperature is around 10°C, and the minimum is around 3°C and falling close to 0°C in some year. However, the maximum temperature goes up to around 27°C even in the coolest season. In this way, the maximum air temperature is more or less constant throughout the year. Therefore, in the dry season, when the minimum air temperature falls down, the diurnal temperature difference is prominent.

The Xe Katam project area is located in an elevation range from 500 to 300 m. On comparison of the data at Nikhon34 and Pakse, the difference in air temperature due to elevation is approximately 0.7°C per 100 m.

when this value is applied, although there will be fluctuation according to the season, the air temperature at the Xe Katam project site is estimated to be about 5°C to 6°C higher than in the upstream basin of the Xe Katam River.

The elevations at the Sekong and the Attapeu which are the service areas of Xe Katam Power Station, are from 100 to 150 m. This is roughly the same elevation as Pakse at the west of the Bolaven Plateau, and it may be estimated that air temperatures at Sekong and Attapeu are more or less the same as at Pakse.

The estimated monthly air temperatures of the Xe Katam intake dam site (approximately EL. 460 m) and the Sekong/Attapeu are given below.

Estimated Temperature at Xe Katam Intake Dam Site (EL 460 m)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Ave. Temp.	21	23	24	25	26	26	26	26	26	25	23	21	24
Max. Temp.	32	33	33	34	33	33	32	32	33	32	32	32	34
Min. Temp.	8	9	16	16	18	21	20	21	18	16	11	9	7

Estimated Temperature at Sekong/Attapeu (EL100 - 150 m)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Ave. Temp.	25	27	29	30	28	27	27	27	27	26	25	23	27
Max. Temp.	34	36	38	38	36	34	33	33	34	34	33	33	38
Min. Temp.	14	16	19	22	22	23	22	22	22	20	17	14	13

(2) Humidity and Evaporation

Observations of relative humidity and evaporation on the Bolaven Plateau are being carried out at Nikhon34 and KM42. The observation records obtained at Nikhon34 which is close to the Xe Katam River Basin are shown in Table III-3-4.

According to the data observed at Nikhon34 Station, humidity in this region is high throughout the year. The mean monthly relative humidity is around 70% even from January to February when it is driest, and around August at the peak of the rainy season it becomes close to 90%. The maximum relative humidity is at a high level of around 95% during through the year. In contrast, the minimum relative humidity in August is at a high level of close to 80%, but in January and February the humidity falls to below 50%.

With regard to evaporation, the observation records at Nikhon34 show a seasonal variation reflecting the minimum humidity in the dry season. According to the observed values, in contrast to the evaporation of 30 mm/month in the rainy season, it become 60 mm/month to 70 mm/month in the dry season. However, since the ground surface is dried in the dry season, the actual evaporation will become lower than the above values.

Regarding annual evaporation, the observed values at Nikhon34 are from 530 mm to 650 mm, and this is only around one third of approximately 1,800 mm observed at Pakse located at west of the Bolaven Plateau. This is thought to be caused because observation of evaporation at Nikhon34 are not made by the Class A pan but by pitcher. The annual evaporation at Nikhon34 is estimated to be from 1,000 to 1,200 mm based on the observed values at Pakse site and taking into consideration the difference of altitude between the two sites. Observed evaporation at Nikhon34 will be this degree of values if it is converted to be the value of Class A pan.

The actual evaporation in a river basin is generally about 70% of the value by the Class A pan. When this is taken into account, actual evaporation at Nikhon34 will be about 800 mm annually. Since the average altitude of 1,050 m of the Xe Katam River Basin is not so different from the altitude of 1,150 m at Nikhon34, the average actual evaporation of the Xe Katam River Basin is estimated to be about 800 mm annually.

(3) Wind Direction and Wind Speed

The observed wind directions and wind speeds at Nikhon34 are shown in Table III-3-5 and Fig. III-3-3.

Winds observed in the area of the Bolaven Plateau are more or less climatic one due to monsoons. In the dry season, the influence of the northeast monsoon is measured and, especially from November to January, winds from north direction become predominant. However, from February to April, the wind direction becomes unstable. From May, when the rainy season begins, the influence of the southwest monsoon is measured. During this season at Nikhon34, except in May, west winds become predominant in June to August, and winds again become unstable in September and October.

On the other hand at the Paksong site located approximately 10 km to the west of Nikhon34, as shown in Fig. III-4-4, southwest winds become predominant in the period from June to August, and east winds are predominant from November to January. In this way, a certain deviation from Nikhon34 is seen regarding wind direction. In view of this, it is considered that wind directions in this region are subject to complex influences due to topography unique to the Bolaven Plateau along with the influences of monsoons.

Wind direction is one of the major factor influencing rainfall, and judging from the trend of rainfall distribution shown in Table III-4-1, it may be estimated that the trend of wind direction in the upper and middle basins of the Xe Katam River will be similar to that at Nikhon34.