4.2 GEOLOGY AROUND PROPOSED RESERVOIR

4.2.1 UPSTREAM AREA OF RESERVOIR

Findings by field reconnaissance in the Thaviang Region are as follows;

B.Phonyeng to B.Xiangkhong: Lower Jurassic folded formations as mudstone, conglomerate and sandstone, weak and fractured, deeply weathered near the boundary with Palaeozoic formations. River banks are found to be eroded by the Nam Ngiep River along roadsides between B.Naxay and B.Viengthong. This is caused by continuous erosion because the flow of the Nam Ngiep attacks the left bank and turns southward from the east. Still, the erosion on the left bank is advancing. According to the aerial photographic analysis, there are west-east lineaments, but there are no landslides found around the river curve.

Near B.Xiangkhong, Palaeozoic formations and granitic rocks are distributed. From B.Phonyeng to B.Phonehom, metamorphosed rocks, greenish with schistosity (NW-SE, near B.Phonehom) conforming to the topography are found. From B.Phonyeng to B.Pou, Lower Jurassic folded formations such as mudstone and sandstone, are seen in the river and riversides.

4.2.2 DOWNSTREAM AREA OF RESERVOIR

In the east of B.Muang Bo, which is 13km north of B.Hatkham, green schist is found at the excavation cut for road construction. Palaeozoic quartzite sandstones are found at the basement of the small dam for agriculture on the Nam Xao River. Mesozoic sandstone was found on the ridge north of B.Nahan (3km south of B.Muangbo). Site inspection was carried out at the Palaeozoic formation near B.Sopyouk (12km northwest of damsite) by jeep access from Muang Hom. Limestone outcrops exist in the village B.Muanghuang (15km north-east of B.Hatkham), and the quarry is working to produce aggregates. At the foot of Mt. Muang (west of B.Muang, 2.5km south-east of B.Muanghuang), Mesozoic sandstone/slate are distributed at the basement of the small agricultural intake facilities under construction. Mesozoic (Lower Jurassic to Triassic) sandstones and mudstones form the "Snake" range, so-called because it ranges from north-west to south-east about 4km east of B.Hatkham. Mesozoic sandstones and mudstones are distributed on Mt.Tek, which ranges from west-north to south-east 2.5km north-west of B.Hatkham, but conglomerate was not found.

4.3 GEOLOGY AT MAIN DAM SITE

4.3.1 GENERAL

Lower cretaceous to Middle Jurassic formations are distributed and make up the almost flat to gently dipped (around 10° to the East) hills with an elevation of 400 m to 700 m on the hilltops. Massive sandstone, conglomerate and red mudstone are distributed in this area. Hard conglomerate, sandstone and mudstone make a gorge and steep valley about 10km east of B.Hatkham, which is the proposed dam site. Topographic profile indicates an inclination of 30° to 33° on both banks around the dam site.

A geological map of the dam site is shown in Figure 4.3.1 including that for the re-regulation dam site. Figure 4.3.2 and Figure 4.3.3 are the survey results shown in plan and section at the dam site. Moreover, the geological profiles along the river diversion tunnel, the spillway chuteway and the headrace tunnel are shown in Figure 4.3.4, Figure 4.3.5, and Figure 4.3.6, respectively.

4.3.2 GEOLOGICAL INVESTIGATIONS

In February 2002, geological investigations comprising core drilling, seismic prospecting and laboratory rock tests were conducted by a local contractor. Drillings are tabulated as in Table 4.3.1 Seismic prospecting was carried out along six (6) lines (2 km in total). Rock tests were conducted for test specimen from the drill cores, 16 from the main dam site, 2 from Sopyok and 2 from Nam Katha. Conglomerate and sandstone from the dam site were tested for potential alkali reactivity of cement-aggregate combinations.

Table 4.3.1 List of Drillings

No.	Name	Depth (m)	Coordinates (E)	Coordinates (N)	G.H.(EL.m)	Location
1	ND1	150	344,459.90	2,062,512.39	321.493	Damsite leftbank
2	ND2	100	344,251.46	2,062,390.35	211.497	Damsiteleft riverside
3	ND3	100	344,203.12	2,062,278.90	205.044	Damsite right riverside
4	ND4	150	344,304.06	2,062,041.60	322.335	Damsite rightbank
5	ND5	100	344,203.12	2,062,278.90	205.044	Damsite right riverside, Folding
6	NR1	20	349,340.69	2,062,541.71	172.442	Re-regulating damsite leftbank
7	NR2	20	349,319.41	2,062,454.84	167.565	Re-regulating damsite rightbank
8	NQ1	50	341,800	2,061,960	325	Nam Katha Quarry
9	NQ2	50	329,863	2,071,591	400	Sopyok Quarry

4.3.3 Geological Distributions and Structure

(1) Geological Formations

According to the drilling results basement rock formations around the dam site were revealed. A drilling (45 degree incline, 100 m length) penetrated into folding structure revealed six formations and folding displaces these on either bank; they are about 70 m relatively higher on the right bank than on the left bank. This displacement is greater than the estimation of 30 to 50 m by field reconnaissance.

On the cliff on the left bank, conglomerate is not so widely distributed and ND1(G.H. 321 m) showed the conglomerate formation is distributed to the depth of 54.6 m, so the layer is still protected from weathering and erosion. On the other hand, ND4 (G.H. 322 m) on the right bank could not be met by this formation because it is distributed higher than EL 340 m and conglomerate formation is widely exposed to weathering and erosion on the hilltop forming deep joints and cracks

Table 4.3.2 Geological Formations and Drillings

Geology	Thickness (m)	Rocks	Found in Drillings
Formation6	100+	Ms > Ss	
Formation5	80	Ss, Cg >> Ms	ND1
Formation4	30	Ms > Ss	ND1,ND4
Formation3	50	Ss > Ms	ND1,ND2,ND3,ND4,ND5
Formation2	40	Ss = Ms	ND1,ND2,ND3,ND4,ND5
Formation1	30+	Ms >> Ss	ND2,ND3,ND4,ND5

Remark: >>、 >、 = denotes relationships in total thickness

(2) Rock Faces

Rocks around the dam sites are conglomerate, sandstone and mudstone. Conglomerate includes many small rock fragments with a maximum diameter of 2 cm, originated from Palaeozoic and volcanic rocks and its matrix has many quartz particles. Sandstone varies from coarse to fine grained and partly alternating with fine silty layers. The layer in ND1 15.6 m to 17.0 m may be chalk (calcareous coarse sandstone) and it will be discussed in the detailed investigation stage.

Mudstone consists of fine grained shale to siltstone, and is volcanic. Mudstone ranges from strong with a solid matrix to weak and characterized by swelling with increased moisture content and weathering. Final classification of mudstone remains to be studied in the detailed investigation stage. Rocks still keep their original sedimentary structure, such as bedding plane and alternation; however, in folded areas the original structure is disturbed and forms a mix of sandstone and mudstone in the order of drilling core (at scales of several centimeters). The finely mixed rock was observed as listed below.

Table 4.3.3 Finely Mixed Rock in the Drilling Cores at Damsite

Drilling Name	Depth (m)	Descriptions	Formation
ND3	46.7-47.8	Ms>Ss	Formation2
	48.6-49.55	Ms>Ss	
ND5	30.8-31.4	Ms>Ss	Formation2
	32.5-33.2	Ms<Ss	
	35.0-36.5	Ms<<Ss	
	37.7-38.6	Ms=Ss	
	39.1-39.5	Ms>Ss	
	46.0-48.8	Ms>Ss	
	49.7-51.7	Ms=Ss	
	54.6-58.8	Ms>Ss	
	94.6-99.4	Ms>>Ss	Formation1

(3) *Folding Structure*

Folding structure runs through the dam site from the upstream left bank to the downstream right bank in the middle of the slope. Outcrops which show gradually increasing dip from 10 degree to 75 degrees reveal the folding structures along the Nam Ngiep River up to its confluence with the Nam Katha River. The area of increasing dip is generally well stratified with partially weak parts along layers with no disturbance of stratification structure. The steepest part of 75 degrees is located about 300 m upstream along the riverside on the right bank. The steepest part becomes gently dipped again (around 15 to 10 degree to the eastward) at a distance of 150 m along the river (about 50m direct distance to the folding axis). However, the returning part is not well outcropped. ND5 is placed to just penetrate this retuning part to reveal the rocks and their continuities.

(4) Loose Talus Deposits

Huge boulders with diameters of about 10 m are heaped up along the Nam Ngiep riverside, and rocks are mainly sandstone on the upstream side and conglomerate on the downstream side. Outcrops are scattered and deeply covered by talus deposits. Deeper loose deposits on the right bank were related to the geological structure. On the other hand hard outcrops were sometimes found on the slopes, so, estimation of loose deposits was deemed difficult in the Phase I Study due to thick vegetation in the jungle. Through the current drilling and seismic survey, the thickness of loose talus deposits on the left bank was estimated as about 5 m, with rocks consisting predominantly of sandstone (Formation3, thickness 50 m), and sandstone and conglomerate (Formation5, thickness 80 m) which provides huge boulders sliding downward to the riverside along the slope.

The hard rock formations of sandstone and conglomerate make staircase-like outcrops and the weak mudstone is weathered and covered deeply by soil and vegetation. On the right bank of the Nam Ngiep River, the folding structure facilitates rock slides and deep weathering creating thick loose deposits of up to 20 m thickness. On the upper part of the slope, geological formations are outside of the folding zone to make a stable steep cliff and outcrops of hard rock. The uppermost layer of conglomerate is weathered with deep joints and cracks due to a wide area of exposure.

(5) River Deposits

The riverbed was not surveyed by drilling during this Phase II Study; therefore, detail of the thickness of river deposits and depth of foundation rocks are to be studied at the detailed design stage. However it is possible to estimate the riverbed foundation rock by the stratigraphy considering the distribution of strong sandstone and weak mudstone.

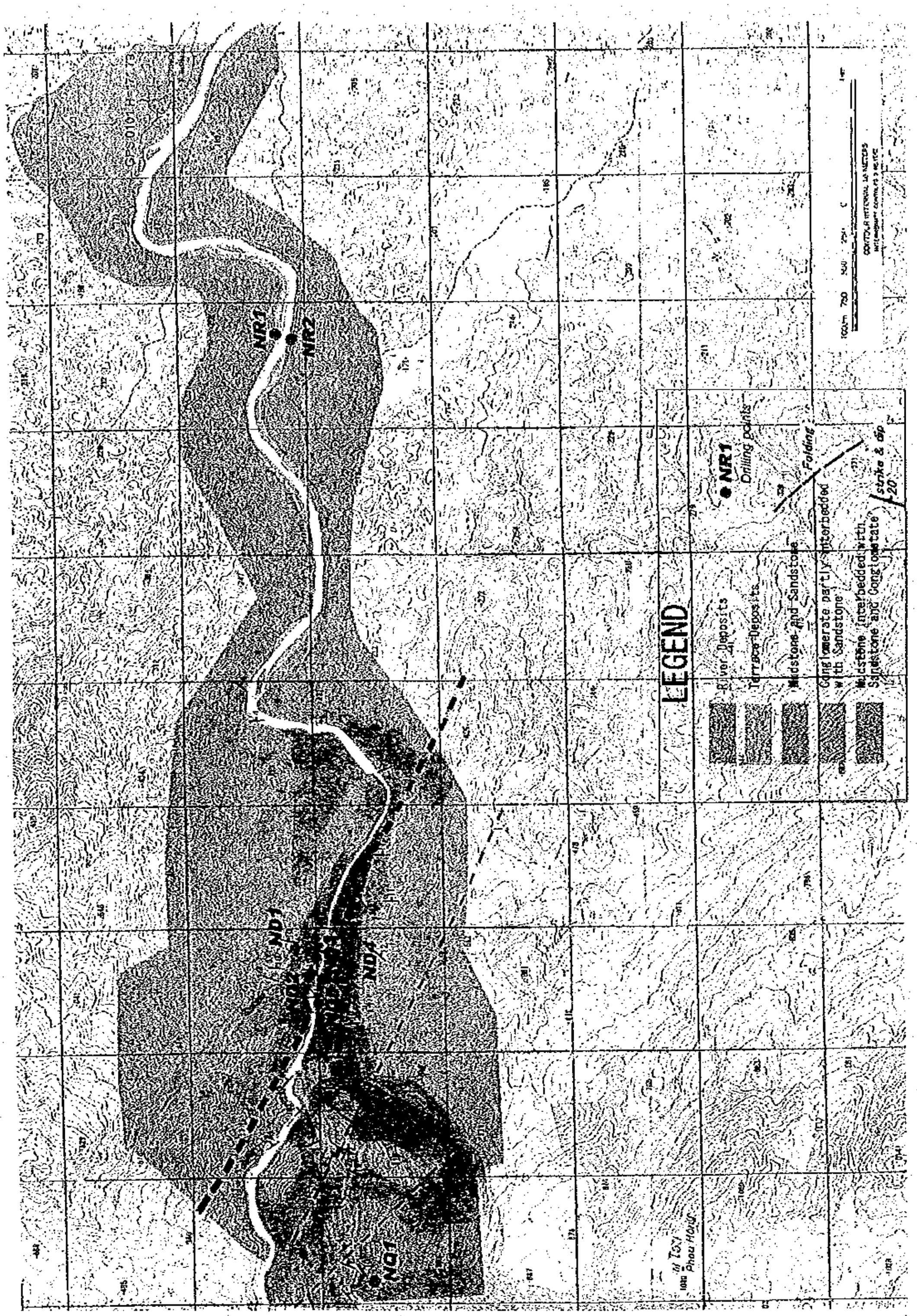
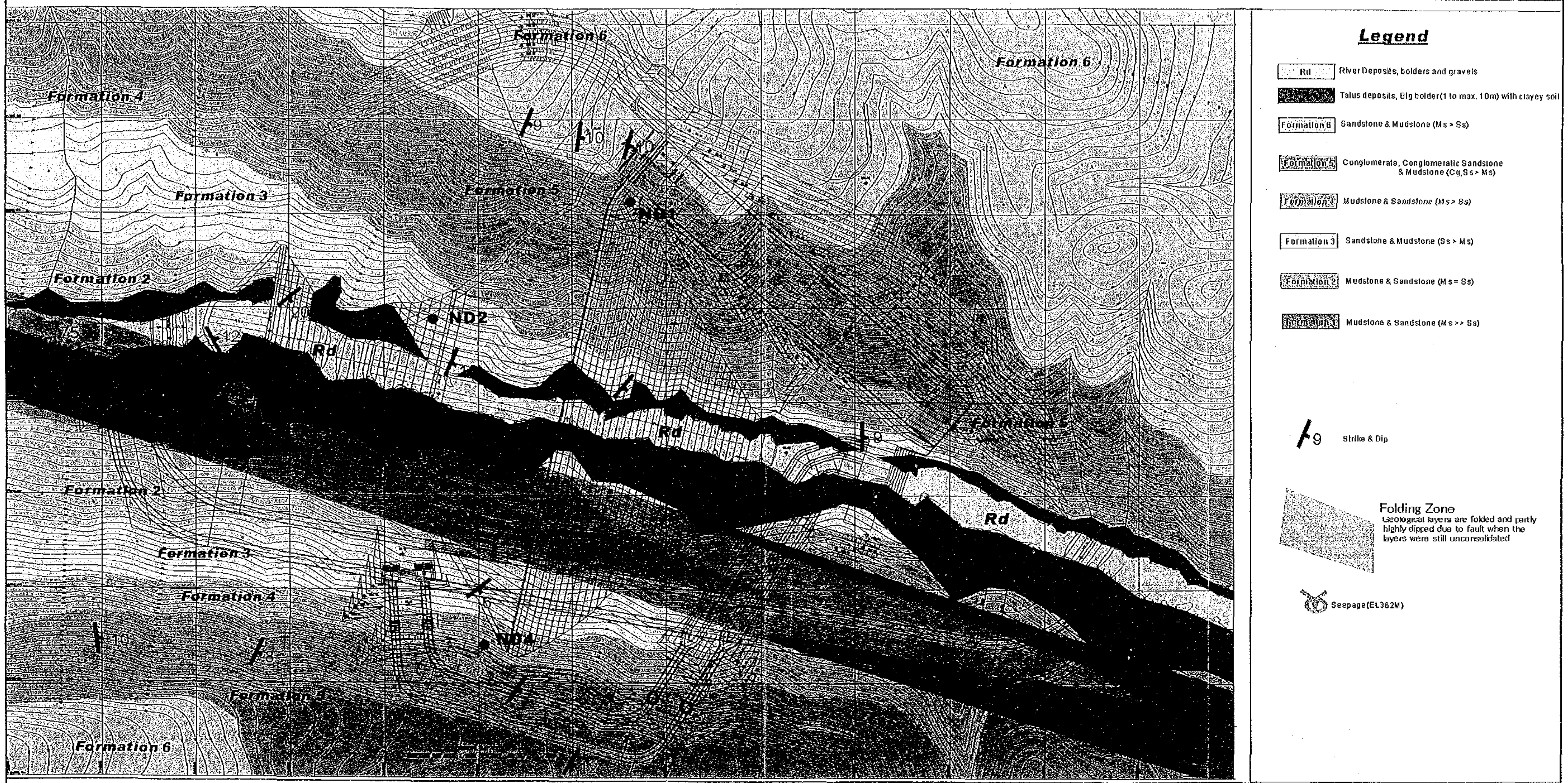
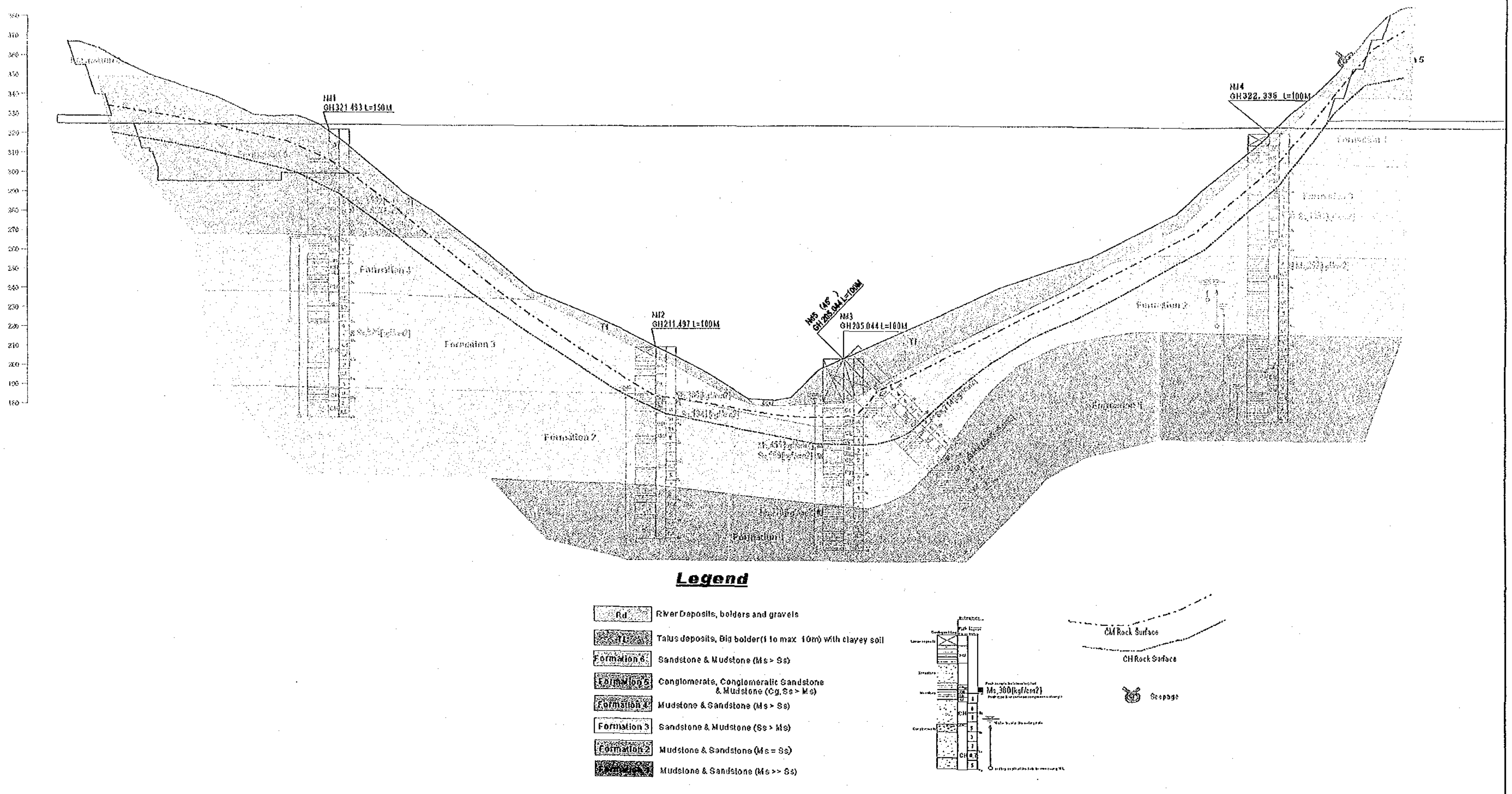


Figure 4.3.1 Geological Map at Dam Site

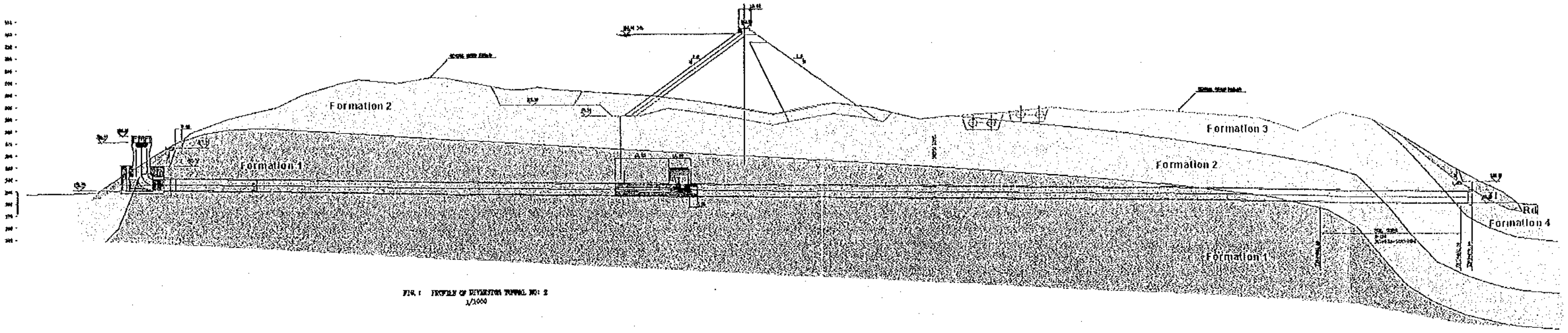


FEASIBILITY STUDY ON THE NAM NGIEP-1 HYDROELECTRIC POWER PROJECT (Phase II) IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC	Figure 4.3.2 Geological Plan at Dam Site
JAPAN INTERNATIONAL COOPERATION AGENCY	

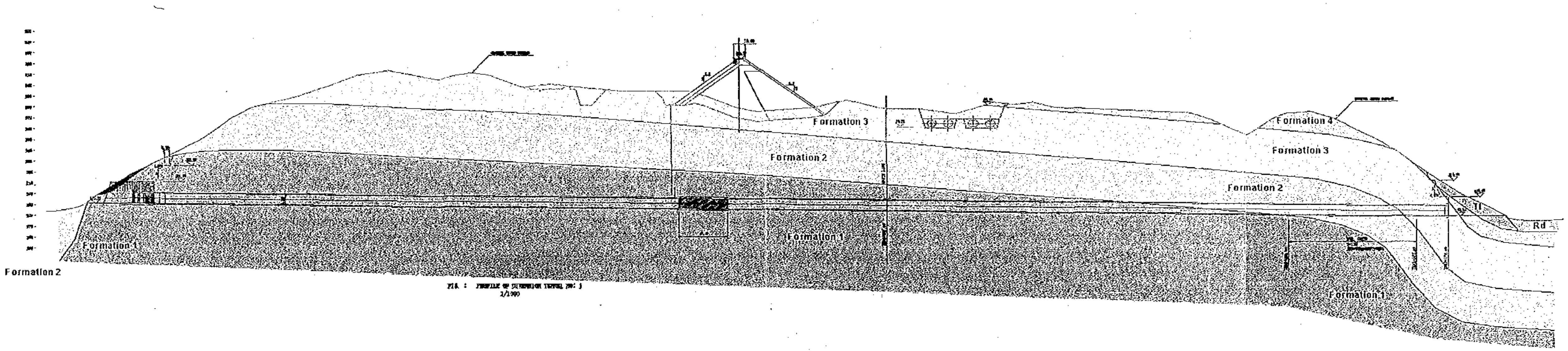


FEASIBILITY STUDY ON THE NAM NGIEP-1 HYDROELECTRIC POWER PROJECT (Phase II) IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC	Figure 4.3.3
JAPAN INTERNATIONAL COOPERATION AGENCY	Geological Profile along Dam Axis

T2



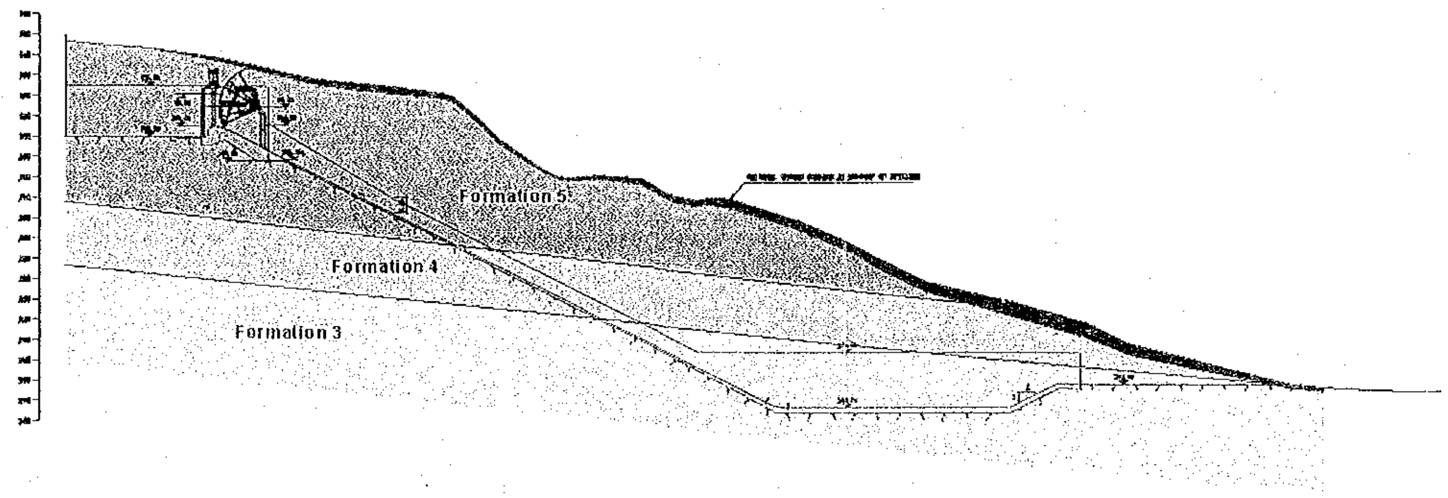
T1



Legend

- Rd — River Deposits, bolders and gravels
- Talus deposits, Big bolder(1 to max 10m) with clayey soil
- Formation 6 — Sandstone & Mudstone (Ms > Ss)
- Formation 5 — Conglomerate, Conglomeratic Sandstone & Mudstone (Cg,Ss > Ms)
- Formation 4 — Mudstone & Sandstone (Ms > Ss)
- Formation 3 — Sandstone & Mudstone (Ss > Ms)
- Formation 2 — Mudstone & Sandstone (Ms= Ss)
- Formation 1 — Mudstone & Sandstone (Ms >> Ss)

FEASIBILITY STUDY ON THE NAM NGIEP-1 HYDROELECTRIC POWER PROJECT (Phase II) IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC	Figure 4.3.4 **Geological Profile along River Diversion Tunnel**
JAPAN INTERNATIONAL COOPERATION AGENCY	



Legend

- Rd — River Deposits, bolders and gravels
- Talus deposits, Big bolder(1 to max. 10m) with clayey soil
- Formation 6 — *Sandstone & Mudstone (Ms > Ss)*
- Formation 5 — Conglomerate, Conglomeratic Sandstone & Mudstone (Cg,Ss > Ms)
- Formation 4 — Mudstone & Sandstone (Ms > Ss)
- Formation 3 — Sandstone & Mudstone (Ss > Ms)
- Formation 2 — Mudstone & Sandstone (Ms= Ss)
- Formation 1 — Mudstone & Sandstone (Ms >> Ss)

FEASIBILITY STUDY ON THE NAM NGIEP-1 HYDROELECTRIC POWER PROJECT (Phase II) IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC JAPAN INTERNATIONAL COOPERATION AGENCY	**Figure 4.3.5** **Geological Profile along Spillway Cuteway**

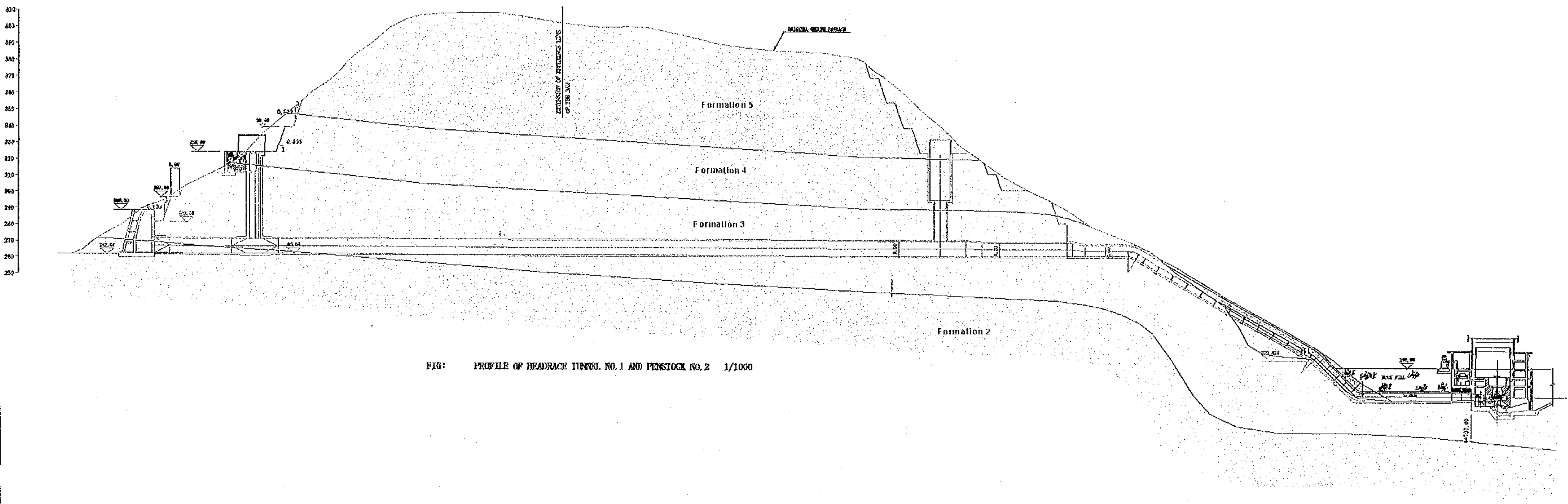


FIG: PROFILE OF HEADRACE TUNNEL NO.1 AND PENSTOCK NO.2 1/1000

Legend

Rd	River Deposits, bolders and gravels
	Talus deposits, Big bolder(1 to max. 10m) with clayey soil
Formation 6	Sandstone & Mudstone (Ms > Ss)
Formation 5	Conglomerate, Conglomeratic Sandstone & Mudstone (Cg,Ss > Ms)
Formation 4	Mudstone & Sandstone (Ms > Ss)
Formation 3	Sandstone & Mudstone (Ss > Ms)
Formation 2	Mudstone & Sandstone (Ms = Ss)
	Mudstone & Sandstone (Ms >> Ss)

FEASIBILITY STUDY
ON THE NAM NGIEP-1 HYDROELECTRIC POWER PROJECT (Phase II)
IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC
JAPAN INTERNATIONAL COOPERATION AGENCY

Figure 4.3.6
Geological Profile along Headrace Tunnel

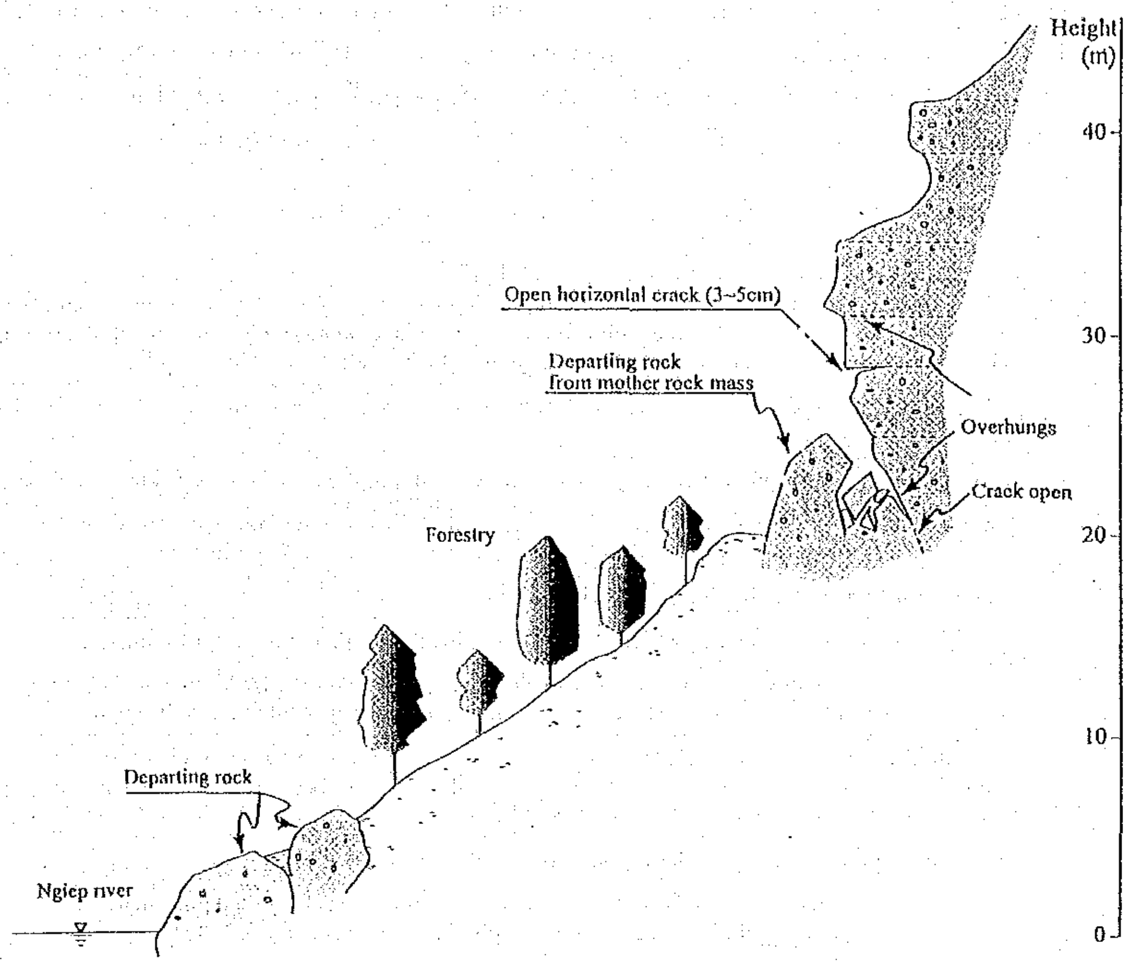


Figure 4.3.7 Sketch of Conglomerate Cliff

4.3.4 STRENGTH AND PERMEABILITY OF DAM FOUNDATION ROCKS

(1) Rock Classification

The rock classification of the Central Research Institute of Electric Power Industry (CRIEP) was applied, as this is used for many hydroelectric power dam projects in Japan. This is applicable to rock masses based on observation of outcrops and adits to classify the rocks into several categories ranging from A, B, CH, CM, CL to the lowest of D, mainly on the strength of the foundation rock.

Table 4.3.4 Classification of Rock at Dam Site

Class	Descriptions
A	Very fresh and intact, constituent minerals and particles are not altered. There are almost no cracks or joints, and even if they exist they are completely closed and weathering is not observed along the face. Rock is very hard. Hammering makes high metallic sound.
B	Very hard. Cracks and joints are strictly closed. However, some constituent minerals and particles are weathered or altered.
CH	Constituent minerals and particles are influenced by weathering except for quartz, but, rock is hard. Strength among joints and cracks altered by pyrite is decreased and the rock can sometimes be separated by strong hammering with clayey thin remnants on the detached surface. Hammering makes metallic but somewhat dull sound.
CM	Constituent minerals and particles are weathered or altered to rather soft except for quartz. Strength among joints or cracks is decreased and hammering makes the rock separate with remnants of a silty layer on the detached surface. Hammering makes a half-metallic but dull sound.
CL	Constituent minerals and particles are weathered and altered but weathering except for quartz and rock is soft. Cohesive strength of joints or cracks is low and rock are broken easily by hammering with clayey materials on the broken surfaces. Hammering makes a non-metallic dull sound.
D	Constituent minerals and particles are strongly weathered and rock is very soft. Strength among cracks and joints is very low and hammering breaks the rock into small pieces. The broken pieces have clayey material on the surfaces. Hammering makes a remarkably non-metallic dull sound.

Observation of drilling cores enables classification of geological logs in the order of tens of centimeters and cores are classified ranging in the same way as A, B, CH, CM, CL and D. Here RQD and core recovery and rock tests are to be considered to make the field standard suitable for the project site.

The drilling cores are classified as shown in Table 4.3.5 below.

Table 4.3.5 Rock Classification and Depth in Drilling Cores

Drilling Name	Rock Surface	D class rock surface	CL class rock surface	CM class rock surface	CH class rock surface
ND1	6.0m	6.0m	9.6m	15m	32.5m
ND2	5.6m	5.6m	13.4m	25.4m	33.9m
ND3	22.6m	22.6m	22.6m	30.0m	45.0m
ND4	5.4m	5.4m	8.7m	15.0m	27.0m
ND5	20.4m	20.4m	20.4m	23.4m	51.7m

The rocks naturally increase in strength to be classified from D to CL, CL to CM, CM to CH with depth because weathering is the main factor affecting the rock strength. However in the folding zone, while rocks will tend to increase in strength gradually with depth, there will be significant irregularity in the strength of rocks rather than a simple and gradual increase in strength.

Table 4.3.6 Scattering Strength of Rocks in the Folding Zone

Rock Class	Definition	Damsite Rock (excluding folding zone)	Damsite Rock (folding zone)
D	Rocks among D and CL lines	Strength increases according to the depth from D to CL	Mainly of D class rocks
CL	Rocks among CL and CM lines	Strength increases according to the depth from CL to D	Mainly of CL and partly of D and CM class rocks
CM	Rocks among CM and CH lines	Strength increases according to the depth from CM to CH	Mainly of CM and partly of D and CL class rocks
CH	Rocks deeper than CH line	Strength increases according to the depth below CH	Mainly of CH class rocks

(2) Erodibility

Concrete face rockfill dam foundations are classified into 4 categories of erodibility(Rem) based rock class as shown in Table 4.3.7. Rocks in the folding zone, especially for CL and CM classes, are evaluated one rank lower compared to the rocks outside the folding zone, considering the scattering strength of rock in the classified zone.

Remark: Reference 「Concrete face rockfill dam foundations. Jesus M. Sierra」

Table 4.3.7 Erodibility and Rock Classification

Foundation Type	Geology	Rock Class
Non-erodible	CM,CH, Ss and Ms	CM,CH rocks(excluding folding zone)
Moderately-erodible	CL Ss, part of CL Ms	CL Ss, CL Ms, CM rocks in the folding zone
Erodible	Part of CL Ms	CL Ms、CL rocks in the folding zone
Highly erodible	D Ss, Ms, and Sheared zone	D Ss, Ms and Sheared zone

In the future investigation, adits will be required to make detailed observation of the surfaces of erodible rocks, inclusions, fragments and soft materials in the cracks and joints. Core recovery must be high enough to collect all the soft materials in the joints and cracks, so, further improvement of drilling technology is to be encouraged together with technical cooperation and assistance.

(3) Groundwater Level

Groundwater in drill hole ND1 on the left bank was found at the depth of GL.-55 m (EL.265 m), the lower part of Formation 5 (formation depth reaches to 54.6 m) which is underlain by mudstone layers of Formation 4. The water table is stable in the dry season. Drill holes ND2 and ND3 near the river have slightly higher water levels than the Ngiep River level. In ND4 borehole, the water level fell as drilling progressed and initially seemed to become stable at around 75 m to 90 m, but finally dropped to 131 m when the drill hole reached the final depth of 150 m.

Table 4.3.8 Final Water Level in Drilling Holes

Name	Depth below Ground Level (GL.m)	Elevation (EL.m)
ND1	55	265
ND2	22	189
ND3	19	186
ND4	131	191

(4) Groundwater Level and Weathering Depth

ND4 is positioned at a ground height of EL.322.3 m in Formation 4. Meanwhile, Formation 5, the layer with groundwater on the left bank is situated above EL.340 m. In fact seepage is well known by local people about 40 m upward from ND4 along a footpath at the foot of the vertical steep cliff at EL.362 m where a bamboo drinking cup is placed for local and ethnic people walking along the footpath. The seepage is in the amount of 2 to 3 liters in the dry season, and was used as a source of drilling water for ND4 delivered through a half-cut bamboo pipe from the seepage point to the site. This shows the mudstone rich Formation 4 makes an impermeable zone that prevents groundwater in Formation 5 from infiltrating very deeply into the underlying layers of Formation 3 and below. Weathering was found in the drilling cores as shown in Table 4.3.9.

Table 4.3.9 Weathering in the Drilling Cores

No.	Weathering Depth (m)	Weakly Weathered Depth (m)	Weathered Joints or Cracks in the Depths (m)
ND1	25.0	57.5	74.3
ND2	33.9	46.8	-
ND3	35.0	42.0	-
ND4	21.3	58.4	130.75
ND5	23.4	47.0	-

In ND4, a weathered joint was recorded at the depth of 130.75 m which corresponds almost to the depth of final water level of the hole. Therefore leakage of water in the drilling hole is estimated to have occurred due to the presence of this joint. The elevation of this water level is a little higher than river level, so the permeable zone caused by folding or steep topography eroded by Ngiep river would be related to this deep weathered joint. One cause of the low water level is the lack of infiltration of groundwater from the overlying Formation 5. Further investigation in the detailed design stage is required.

(5) Vacancies in the Basement Rocks

Irregular small vacancies with of diameters(longitudinal) 5 mm to 1 cm which seem to have melted by alteration are found. Though there is no indications of relation to higher Lugeon values, still attentions are to be paid in relation to folding structure and groundwater level.

Table 4.3.10 Vacancies and Formations

Drilling Name	Depth (m)	Formation	Rock
Nd1	55.4-55.5	Formation5	Ss
	55.5-56.0		Ms
	91.2-91.5	Formation3	Ms
Nd4	51.2-51.35	Formation3	Ss
	75.5-77	Formation2	Ms & Ss
	121-121.7	Formation1	Ss,crack
Nd5	28.5-30.0	Formation2	Ms
	35.75-36.3		Ss>Ms Mixed
	45.4-46.0		Ss
	50.8-51.7		Ss=Ms Mixed
	59.4-60		Ms>Ss
	60.0-60.5		Ss
	68.5-69.7		Ss

(6) Lugeon Tests

The permeability of foundation rocks was investigated by Lugeon Tests. The tests were conducted upon descending stages of every 5 m. However, the applied pneumatic packer air pressures were not believed to be enough for the maximum 100 m of water pressure, so, re-testing was performed in three of the drilling holes (ND2 was excluded) using a double packer at every 5 m distance. Some distances near the surface (especially CL and partly CM classes) could not be tested.

Table 4.3.11 Lugeon Tests

Drilling Hole	Lugeon Tests (Rocks excluding loose deposits) (m)
ND1	30-150 (6.0-150)
ND2	30-100 (5.6-100)
ND3	30-100 (22.6-100)
ND4	20-150 (5.4-100)
ND5	25-100 (20.4-100)

The distribution of Lugeon values are as shown in Table 4.3.12.

Table 4.3.12 Lugeon Values and Rock Class

Drilling Hole	Tests in CL class	Lu Value (Lu)	Tests in CM class	Lu Value (Lu)	Tests in CH class	Lu Value (Lu)
ND1	0	-	0	-	24	0-2.5
ND2	0	-	1	7.7	13	0-15.1
ND3	0	-	3	1.2-3.8	11	0-2.7
ND4	0	-	1	3.9	25	0-3.0
ND5	0	-	5	2.1-6.1	10	0-5.7

CH class rocks have Lugeon values of 0～5 Lu, i.e., low permeability. CM class rocks have values of 2～10 Lu, meanwhile CL class rocks have values of more than 10 Lu, i.e., high permeability.

(7) Rock Tests

Rock test samples of CH class rocks were taken from fresh drilling cores. The laboratory test results are summarized in Table 4.3.13.

Table 4.3.13 Laboratory Rock Test Results (Rem) 1 MP=10.1972 kgf/cm2

Drilling Name	Sample	Depth (GL-m)	Formation	Rock	Unit Weight (ton/m^3)	Water Content (%)	Specific Gravity	Unconfined strength (kgf/cm^2)	Vp (km/s)
ND-1	R-1	53-54	Formation5	Cg, Ss	2.61			2032.6	3.60
	R-2	41-42		Cg	2.58	0.79	2.62	996.9	3.23
	R-3	36-37		Ss	2.61	0.87	2.61	1552.3	3.18
	R-4	47-48		Ss	2.66	0.67	2.69	709.5	4.67
	R-5	69-70	Formation4	Ms	2.70	1.34	2.66	506.2	4.47
	R-8	107-108	Formation3	Ss	2.62	0.96	2.61	925.4	3.98
ND-2	R-6	36-37	Formation2	Ss	2.68	0.39	2.69	1340.7	5.02
	R-9	28-29		Ms	2.7	1.68	2.64	379.8	3.78
ND-3	R-10	45-46	Formation2	Ms	2.71	1.05	2.69	454.5	4.34
	R-13	52-53	Formation2	Ss	2.58	0.48	2.64	598.6	3.78
	R-15	81-82	Formation1	Ms	2.7	1.20	2.67	770.2	4.64
ND-4	R-7	42-43	Formation3	Ss	2.59	1.08	2.6	1404.0	3.67
	R-12	68-69	Formation2	Ms	2.72	1.24	2.69	251.9	2.78
ND-5	R-11	56-57	Formation2	Ms	2.61	2.99	2.54	554.0	3.05
	R-14	53-54		Ss	2.51	1.13	2.6	714.0	3.53
	R-16	81-82	Formation1	Ms	2.7	0.43	2.7	589.9	5.29
NQ-1	R-17	35.15-35.70		Ms	2.69	1.25	2.6	567.1	3.27
NQ-1	R-18	45.00-45.30		Ss	2.7	0.25	2.69	2030.0	4.00
NQ-2	R-19	38-42.6	Weathered	Granite	2.55	0.65	2.64	221.8	3.02
NQ-2	R-20	43-48	Weathered	Granite	2.52	1.39	2.65	184.9	3.02

Unconfined strengths of different rock types were as follows: conglomerate 1000～2000 kgf/cm^2 (two samples), sandstone 600～1500 kgf/cm^2 (seven samples), mudstone 250～770 kgf/cm^2 (seven samples including two samples [R-5, R-11] re-tested due to the first specimen being broken during its preparation). Sandstone and conglomerate were found to be strong enough for the dam foundation. The strength of mudstone is partly strong enough with stable outcrops and partly not so strong as to swell by increasing moisture or by weathering. Slaking of mudstone is to be studied in the detailed design stage to specify the possible slaking layers and to take necessary measures through design criteria. Mudstone is strong enough as fresh rock, but must be treated with care.

The results of Franklin tests for the Pre-F/S conducted in 1990 indicated ground surface strength as shown in Table 4.3.14 under the Rock Classification by ISRM Uniaxial Strength.

Table 4.3.14 Result of Franklin Test made in Pre-F/S

No.	Rock	Uni-axial compressive strength (Mpa)	Characteristics	Natural moisture content (%)	Unit weight (kg/m^3)
1.	Conglomerate	44 - 64	Medium strength	< 2	2.5
2.	Sandstone	8 - 74	Low to Moderate strength	2 - 6	2.3 - 2.5
3.	Mudstone	2 - 10	Very low to Low strength	6 - 12	2.1 - 2.5

Test results of Phase II are slightly higher than the results in the Pre-F/S stage. This is because the drilled cores in Phase II have been taken from fresh rock (CH). In the Pre-F/S stage, on the other hand, rocks were sampled from ground surfaces that were subject to weathering.

4.3.5 GEOLOGY AROUND RE-REGULATING WEIR SITE

The re-regulating weir is planned to be located 5 km downstream of the dam site, where low hills of 210 –230 m elevation exist. These hills are composed mainly of middle Jurassic to lower Cretaceous reddish mudstone and sandstone. Alluvial deposits are only in the riverbed, and a limited extent of terrace deposits are distributed along the riverside. On parts of both banks there are outcrops of reddish mudstone, so alluvial river deposits are not expected to be deep (maybe less than 2 m). On both banks there are many small branch valleys where foundation rock, mudstone and sandstone, are expected to be encountered under a shallow weathered decomposed zone.

According to the drilling results, at ND1 (left bank) the foundation rock of mudstone occurs at a depth of 6.7 m and at ND2 (right bank) at a depth of 1.5 m. The covering of loose deposits is composed of river sand and gravel.

4.4 SEISMICITY

According to MIH, there is no seismological station in Lao PDR. The following three (3) reports on seismicity in Lao PDR were reviewed:

(i) The Nam Ngiep-I, Pre-F/S, January 1991 by Sogreah.

(ii) The Nam Mo HEPP, Pre-F/S Main Project Report (draft), September 1997, by Electrowatt Engineering.

(iii) The Nam Ngum-3 HEPP, Pre-F/S, Final Report, March 1996 by SMEC.

According to the above report (i), seismic activities in the Nam Ngiep river basin are rare and during the past 20 years, there is no record of an earthquake exceeding magnitude-5.

According to the report (ii), which was written for the Nam Mo river basin east of the Nam Ngiep river basin, there are no earthquake records exceeding Magnitude-6 and very few below magnitude-6 in the central area: 96°-109° east and 10°-25° north of Lao PDR. This report is based on the records observed from 1912 to 1976 by National Geographical Center, Colorado USA.

Report (iii) presents an analysis made by the Seismic Research Centre at RMIT University for all 2,100 seismic records in ever recorded from the south-east Asian countries. The results confirmed that seismic activities in the central region of Lao PDR are very rare.

4.5 CONSTRUCTION MATERIAL

4.5.1 STRENGTH OF ROCK

Mesozoic conglomerate , sandstone and mudstone are distributed around the dam site, and the laboratory rock test results are as shown in Table 3.3.12 above. Conglomerate has an unconfined strength of 1000～2000 kgf/cm², unit weight of 2.6 ton/m³, and water content of 0.8%. Sandstone has an unconfined strength of 600～1500 kgf/cm², unit weight of 2.5～2.7 ton/m³, and water content of 0.25～1.1%. Mudstone has an unconfined strength of 250～770 kgf/cm², unit weight of 2.7 ton/m³, and water content of 0.4～3.0% as indicated by seven samples. The strength of mudstone ranges widely from strong to weak, the latter being associated with high rock water content. Sandstone and mudstone from Nam Katha quarry are stronger than those from the dam site because they belong to deeper geological formations. It is also reported that NQ1 has intrusive rock at a depth between 27 to 30 m, which may possibly have strengthened the surrounding rock.

Sandstone and conglomerate are strong enough and were tested according to ASTMC227, "Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)". According to the appendix of ASTM C33, expansion is considered excessive if it exceeds 0.05% at 3 months or 0.10% at 6 months. The sample here exceeds 0.1% at two weeks so they could cause expansive reactions in cement-aggregate combinations.

Table 4.5.1 Potential Alkali Reactivity of Cement-Aggregate Combinations(Mortar-Bar Method) ASTMC227

Drilling Name	Sample	Depth(m)	Rock	Curing in moist room 24 hrs. 1 day	Curing in water 80°c for 24 hrs. (total of 48 hrs.) 2days (%)	Curing 14days strain(%)	Axial strain 14 days - Axial strain 2 days Strain (%)
ND-1	C-1	42-43	Conglomerate	0.000	0.121	0.334	0.213
ND-1	C-2	110-111	Sandstone	0.000	0.107	0.232	0.125

Remark: Cement is Portland cement Type I

Palaeozoic limestone is located at an existing quarry site in Van Muanghuang about 20 km north-east of the dam site. Rock tests have not yet been conducted.

In potential quarry site B.Sopyok that is located in north and upstream of the dam site, NQ2 was drilled to a depth of 50 m on the ridge. The weathering zone is deep, about 30 m, and at a depth of 50 m fresh rock was still not encountered. Two rock test specimens were taken from the depths of 30 to 50 m in weathered granite and had an unconfined strength of 180~220 kgf/cm^2, unit weight of 2.5 ton/m^3, and water content of 0.6~1.4%. Fresh granite will be available somewhat deeper than 50 m.

4.5.2 QUARRY

(1) Rock Materials

Conglomerate and sandstone are abundantly distributed around the dam site and are expected to be used for rockfill material. Conglomerate is located in Formation 5 (thickness 80 m) (i) on the hilly cliff top area on both sides of the Nam Ngiep River, and (ii) from excavation of the spillway and other excavations. Sandstone exists in various locations, especially in Formation 5 and Formation 3 (thickness 50 m). A sandstone rich formation is to be surveyed for alternation area. In addition, big boulders along the Nam Ngiep riverside and gravel along H.Katha are available for rockfill material, some of which requires crushing.

(2) Concrete Aggregates

Conglomerate and sandstone are also expected to be used as concrete aggregate. However, these still remain to be studied:

(i) Strength of sandstone and conglomerate (crushing ability into aggregate size), and

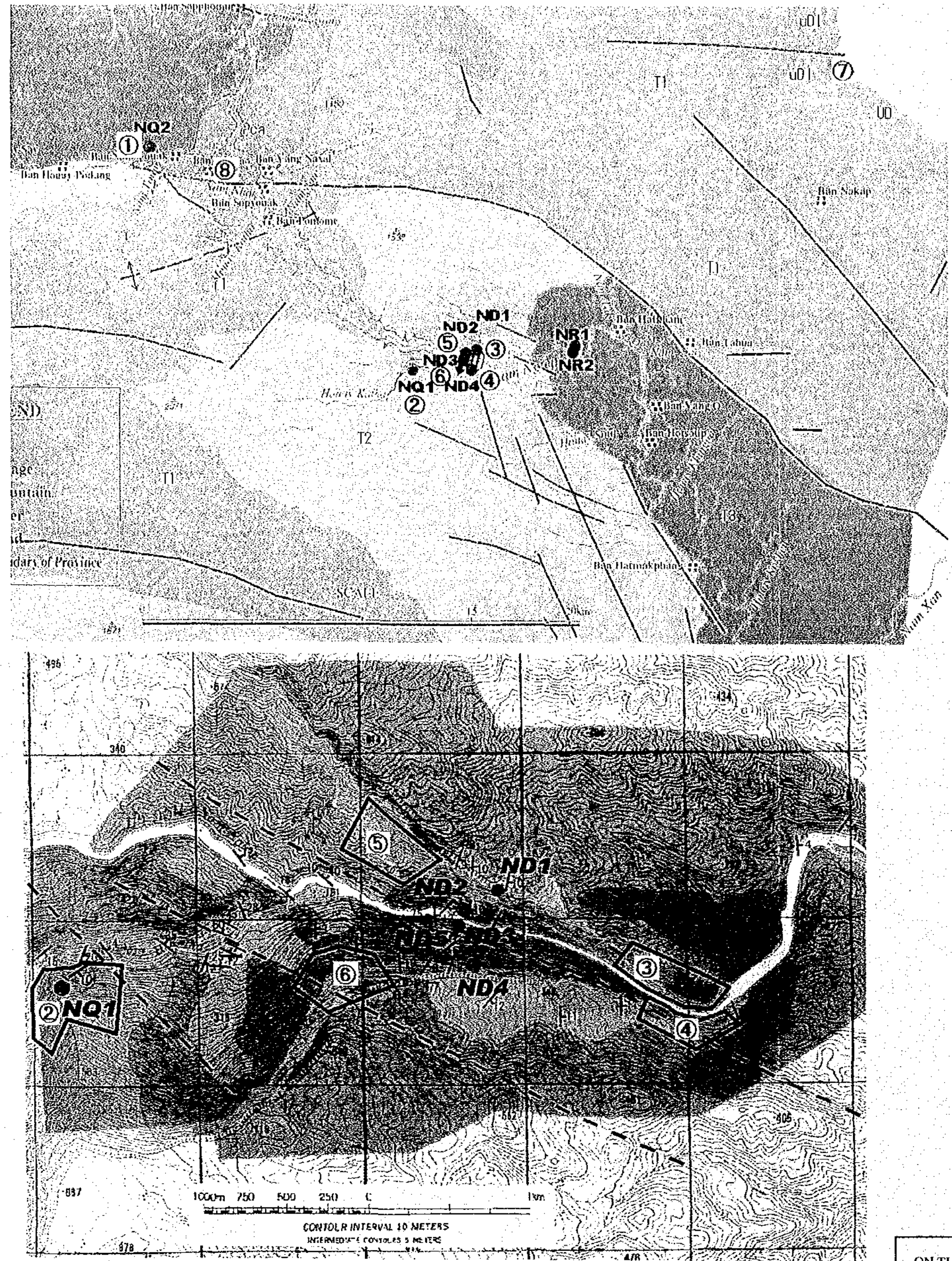
(ii) Alkaline chemical reaction to cement (secondary silica to be checked). Samples from the damsite were tested for potential alkali reactivity (ASTMC227) and they may be susceptible to expansive reaction if used as aggregates.

Other resources for concrete aggregate are from the Palaeozoic formations and from the intrusive granite. They are distributed in the folded late Palaeozoic formations which are located about 12-15 km north of the damsite (Palaeozoic and granite) where the access road along the Nam Ngiep River is to be constructed. At B.Sopyouk, granite was found in drill hole NQ2; however, weathering exists to a depth of 30 m and at 50 m fresh granite still was not available. However fresh granite is distributed in the stream or at the foot of the slopes. Further field reconnaissance is required to find a better quarry site with a shallow weathering zone.

On the northside of the B.Hatkham Palaeozoic formation, limestone and sandstone are available, and in Muanghuang a limestone quarry is working. Direct distance from the dam site is 20 km, but it takes more than one hour via B.Muangbo from B.Hatkham and difficulties arise in road transportation in the rainy season. The locations of site reconnaissance for rock quarries carried out around the dam site are shown in Figure 4.5.1.

(3) Other Materials

River sand and gravel deposits are distributed in the bed of the Nam Ngiep River, from the dam site to downstream of B.Hatkham; however large amounts of good material, free of fine materials such as silt, are not expected. Conglomerate and sandstone are in higher concentrations than in the Palaeozoic formations.



Quarry Sites

① Sopyok Granite(weathering 30m deep)

② Nam Katha Sandstone and Mudstone

③ ④ ⑤ ⑥ Around damsite conglomerate and sandstone are available from Formation3 and Formation5. Rocks are supplied from excavation of spillway and tunnels.

⑦ Muanghuang Limestone

⑧ Sopyok Palaeozoic Sandstone and Mudstone

FEASIBILITY STUDY ON THE NAM NGIEP-1 HYDROELECTRIC POWER PROJECT (Phase II) IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC JAPAN INTERNATIONAL COOPERATION AGENCY	Figure 4.5.1 Prospective Quarry Sites

4.6 CONCLUSIONS AND RECOMMENDATIONS

4.6.1 CONCLUSIONS

Damsite is made up of layers of sandstone, conglomerate and sandstone. Loose talus deposits are about 5m in thickness, especially about 20m thick at the folding on the rightbank. CL class rock is fond at 10m deep ,CM class rock at 15~20m deep, and CH class rock abou 30m deep. However, around the folding on the rightbank CM class rock is found about 30m deep and CH class about 50m deep. Unconfined strengths of sandstone and conglomerate are 600~2000 [kgf/cm^2] and mudstone 200~800 [kgf/cm^2] which are strong enough for the CFRD type dam foundation. Lugeon values for CM class rocks are 2~10Lu, and CH class rocks are 0 ~5Lu which permeability is low enough for the CFRD type dam foundation. In addition curtain grouting will make sure of watertightness of foundation rocks.

Rock material is available abundantly around damsite. Concrete aggregate will be available from granite, at Sopyok upstream of damsite, however, further investigation to make sure of the distribution of fresh hard granite is required due to thick weathering depth.

4.6.2 RECOMMENDATIONS

Recommendations for detailed design stage are as follows;

(i) Drillings at the riverbed are required.

(ii) Vertical cracks and joints are carefully surveyed for spillway.

(iii) Around folding careful drilling to get fully cores are inevitable where original sedimentation structures are disturbed by folding structure ,to make sure if there is clay or fractures. Erodibility is to be studied based on drilling results.

(iv) Groundwater level on the right bank is to be studied further by drillings and Lugeon tests to make sure of watertightness.

(v) Mudstone is to be studied to specify the part for swelling and deteriorating.

(vi) Concrete aggregate quarry is to be surveyed for three candidates. For the first granite around Sopyok is most possible ,but , geological reconnaissance to find hard granite is required. The second is Nam Katha quarry where the most underlying formations around damsite are distributed and still to be tested for potential alkali reactivity. The third is rocks around damsite , which still remains as a candidate because a part of rocks may still be judged available by detailed tests.