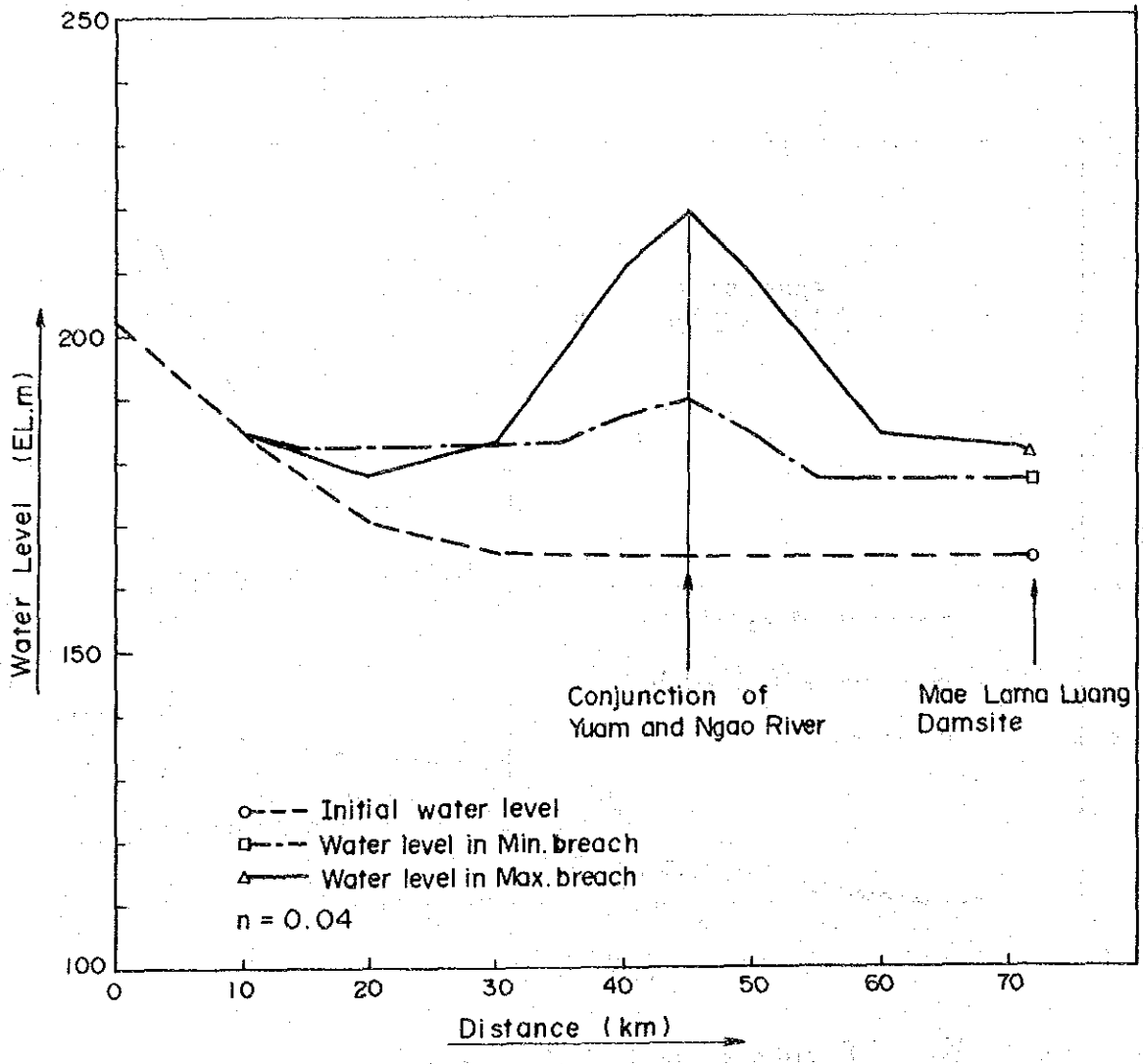

Fig. 5-35 Profile of Maximum Water Level of Yuam River Due to Breach of Nam Ngao Dam

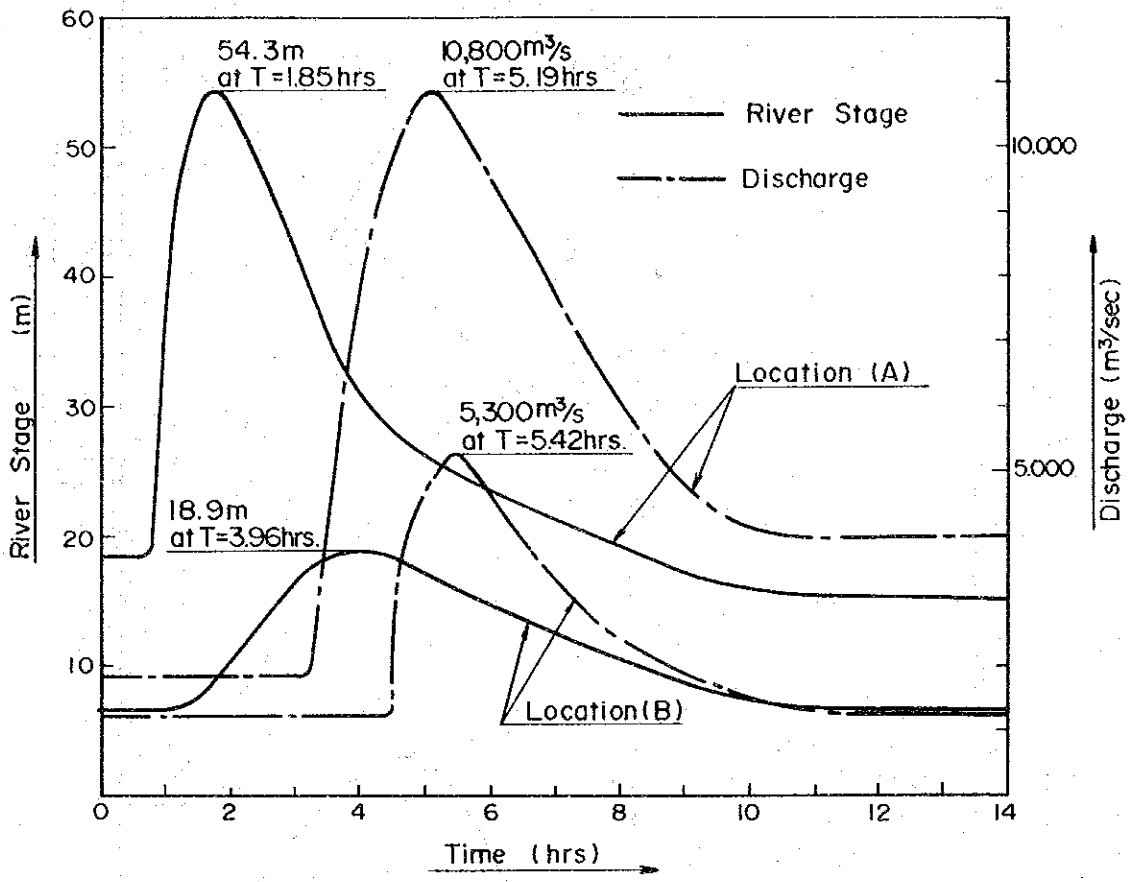

Fig. 5 - 36 Attenuation of Break Flood of Nam Ngao Dam Along Upstream of Conjunction of Yuam and Ngao River

Note : Location (A) — 8 km upstream of the conjunction
Location (B) — 21 km upstream of the conjunction
Maximum breach at n=0.04

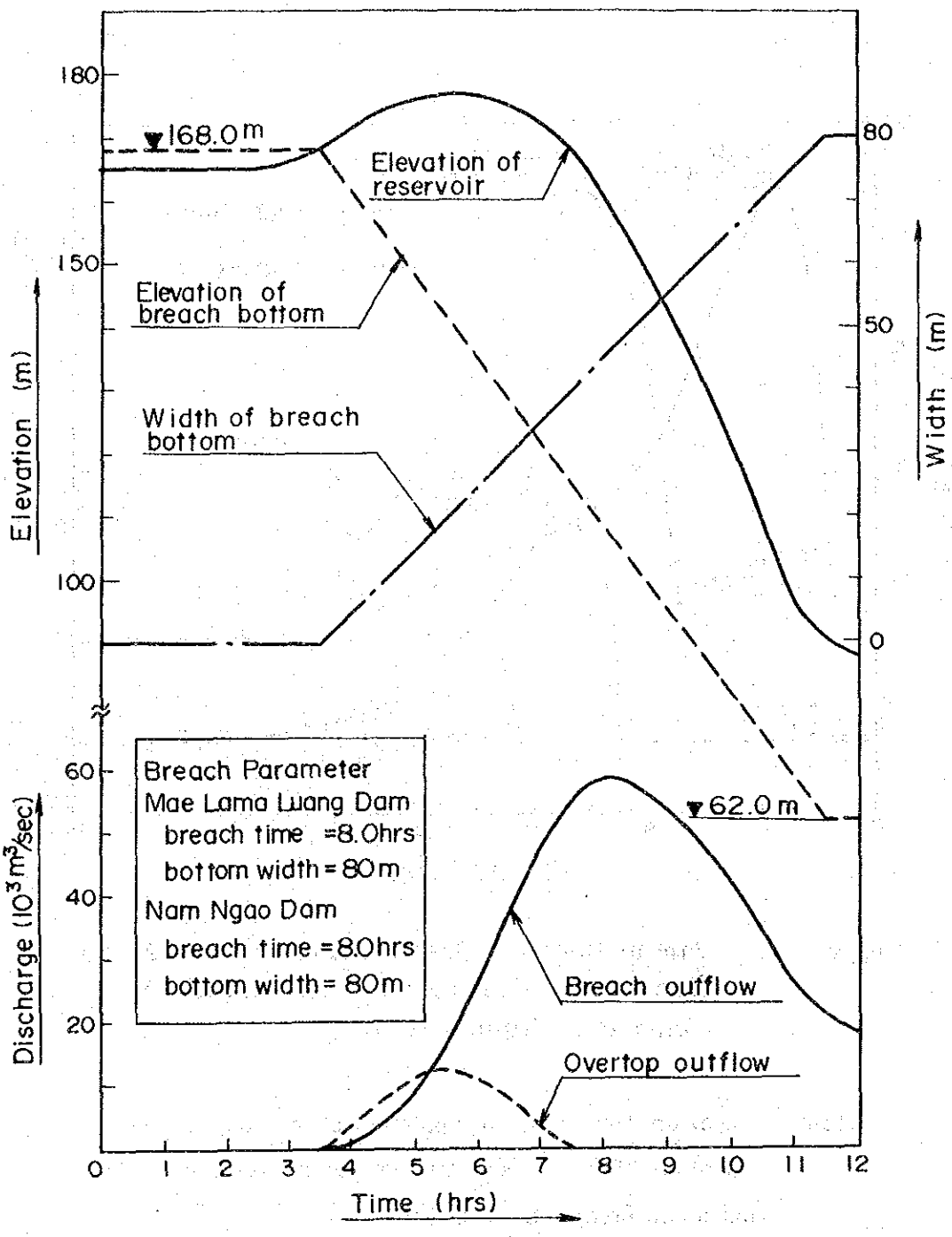

Fig.5-37 Breach Formation and Outflow of Mae Lama Luang Dam Due to Nam Ngao Dam Breach in Min. Case

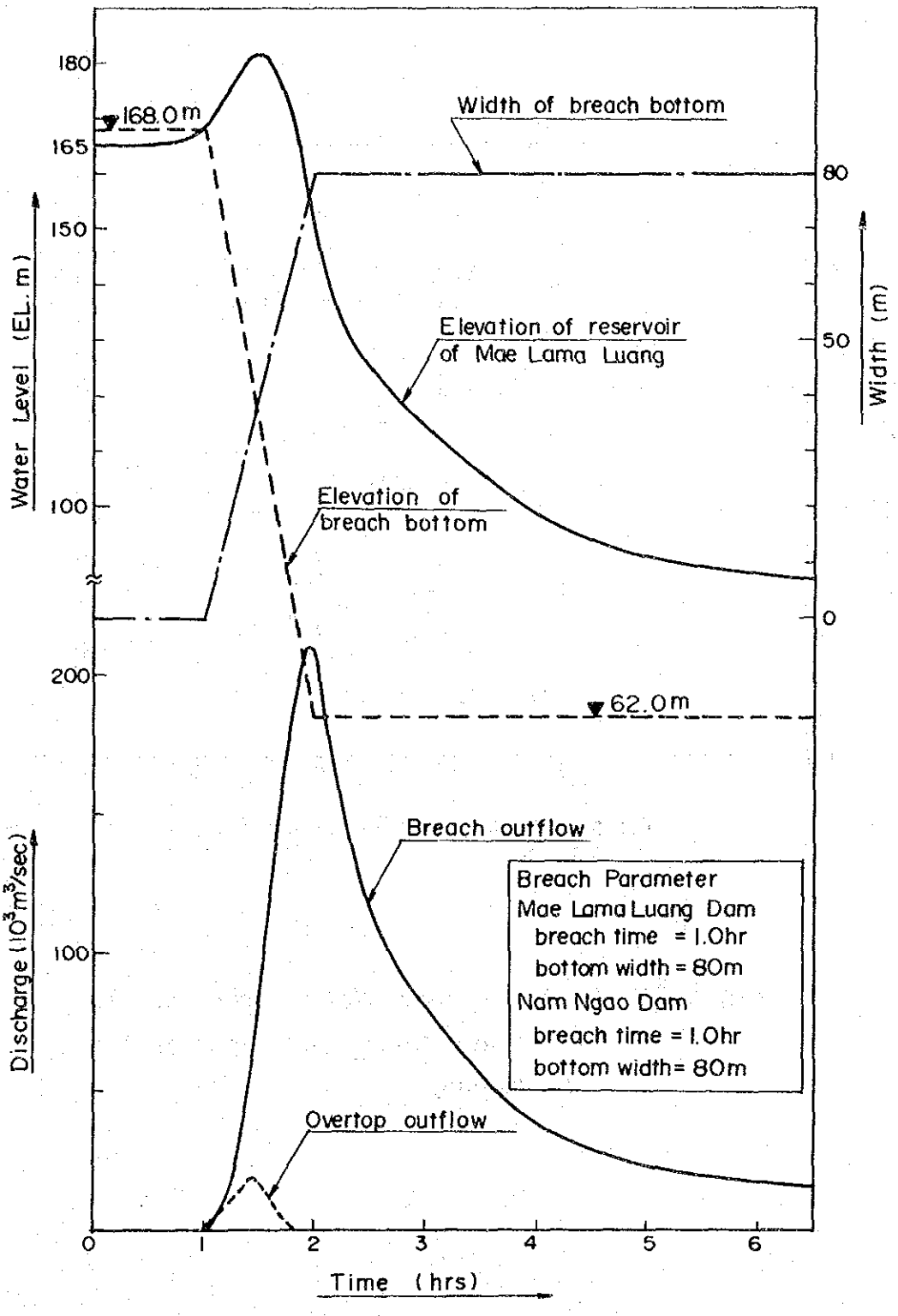

Fig.5-38 **Breach Formation and Outflow of Mae Lama Luang Dam due to Nam Ngao Dam Breach in Max. Case**

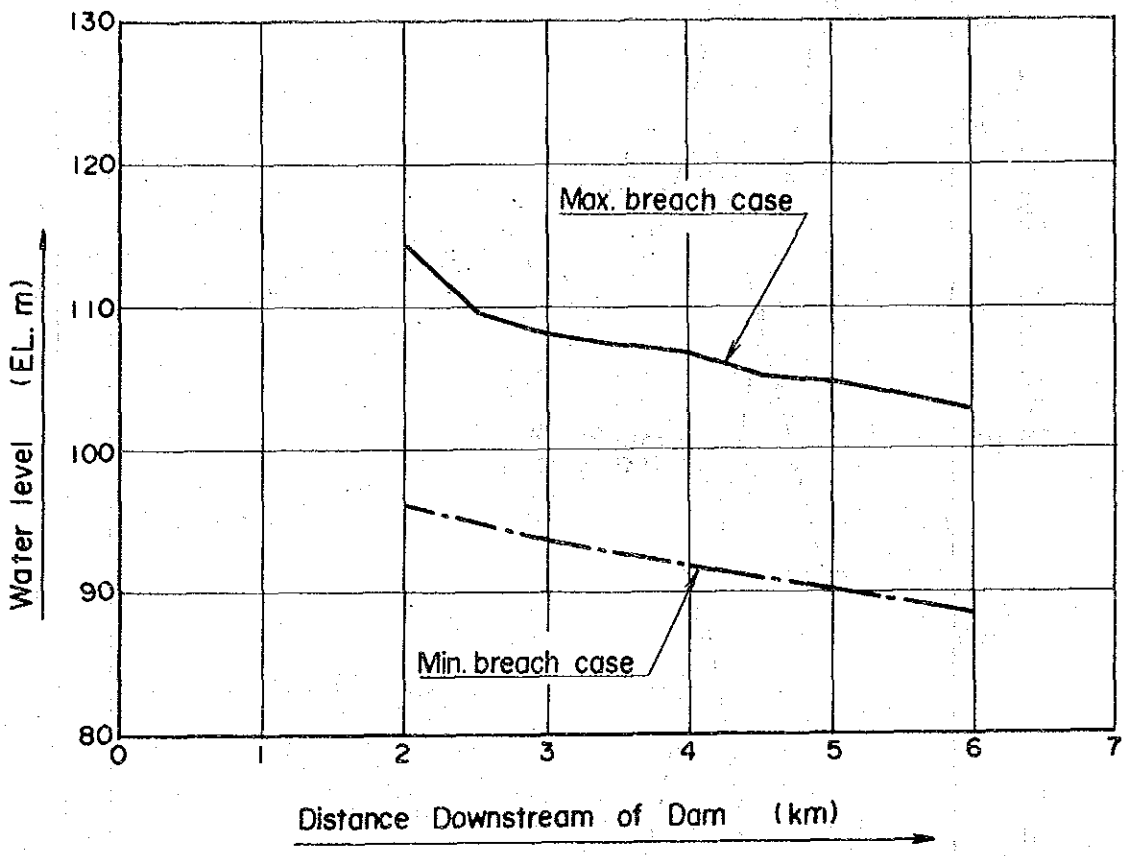

Fig. 5-39 Profile of Max. Water Level Due To Mae Lama Luang Dam Breach By Overtopping

5.8 Hydrological Forecasting System

5.8.1 Purpose of System

Hydrological forecasting is the prior estimate of future states of hydrological phenomena in real time.

The subject of hydrological forecasting should not be viewed as one particular hydrological technique, but as an economic activity using many technological developments, both hydrological and non-hydrological. Thus a prior knowledge of hydrological analysis and modelling, of network design techniques, of telecommunications, of on-line and off-line computer use, etc., is necessary if the activity of hydrological forecasting is to be exercised successfully and efficiently.

Purposes of the hydrological forecasting system in the Yuam river basin are summarized below.

- Optimize operation, regulation and management of the Yuam river
- Provide safety for people and livestock against floods
- Minimize the damages to the irrigation works
- Aid in planning and taking measures to prevent damages to property

5.8.2 Hydrological Forecasting System in the Yuam River Basin

The hydrological forecasting system in the Yuam river basin is to be composed of three different systems; observatory telemeter system, central control system of spillway gates, flood warning system. The installation cost of these systems are roughly estimated as follows.

- Observatory telemeter system 50 million Baht
- Central control system of spillway gates
  - Nam Ngao dam 85 million Baht
  - Mae Lama Luang dam 72 million Baht
- Flood warning system 70 million Baht

(1) Observatory Telemeter System

Data of rainfall and river stage are to be collected at 12 rainfall stations and 5 gauging stations, and to be transmitted through relay stations to the Nam Ngao dam or the Mae Lama Luang dam by VHF radio wave at a required interval. Locations of rainfall stations, gauging stations and VHF relay stations are indicated in Fig. 5-40.

Installation cost of observatory telemeter system was roughly estimated 50 million Baht as shown below.

Installation Cost of Observatory Telemeter System

(Million Baht)

Item	Unit	Quantity	Unit Cost	Cost
1. Rainfall St. 1)	Station	12	2.0	24.0
2. Gauging St. 2)	Station	5	2.4	12.0
3. VHF Relay St. 3)	Station	2	3.2	6.4
4. Main Terminal 3)	Station	1	4	4.0
5. Others	L.S.	1	-	3.6
Total				50.0

Note 1) Installation cost of rainfall stations or gauging stations includes measuring equipment (rainfall, river-stage), radio equipment, solar battery, auxiliary equipment, a house and installation.

2) Installation cost of VHF relay stations includes VHF relay equipment, solar battery, auxiliary equipment, a house and installation.

3) Main terminal at the Mae Lama Luang power station includes main observatory equipment, printing device, control panel, auxiliary equipment and installation.

(2) Central Control System of Spillway Gates

The central control system of spillway gates includes forecasting models of reservoir inflow in development and operational mode, observatory and control equipment of reservoir water level and gates' opening, automatic control code of spillway gates. The system is illustrated in Fig. 5-41.

Installation cost of central control system of spillway gates was roughly estimated 85 million Baht at the Nam Ngao dam and 72 million Baht at the Mae Lama Luang dam as shown in the following tables.

Installation Cost of Central Control System of Spillway Gates at Nam Ngao Dam

(million Baht)

Item	Unit	Quantity	Unit Cost	Cost
1. Automatic Control Equipment of Gates	L.S.	1	-	12.6
2. Water-level Meter	unit	2	2	4.0
3. Gate-opening Meter	unit	2	1.4	2.8
4. Gate-operating Board	unit	2	2	4.0
5. Relay Equipment of Rainfall & Water-level 1)	L.S.	1	-	2.4
6. Cyclic Digital Telemeter	L.S.	1	-	8.0
7. Installation	L.S.	1	-	2.0
8. Industrial Television System 2)	L.S.	1	-	46.0
9. Others	L.S.	1	-	3.2
Total				85.0

Note 1) Data of rainfall and reservoir water level are to be transmitted from the Nam Ngao dam to the Mae Lama Luang dam.

2) Remote control of spillway gates of the Nam Ngao dam can be done at the Mae Lama Luang dam through this ITV system.

Installation Cost of Central Control System of Spillway Gates at Mae Lama Luang Dam

(million Baht)

Item	Unit	Quantity	Unit Cost	Cost
1. Automatic Control Equipment of Gates	L.S.	1	-	11.2
2. Observatory & Control Equipment	L.S.	1	-	9.0
3. Computer Program for Control	L.S.	1	-	9.0
4. Computer Program for Forecasting	L.S.	1	-	10.0
5. Cyclic Digital Telemeter	L.S.	1	-	8.0
6. Water-level Meter	unit	2	2	4.0
7. Gate-opening Meter	unit	4	1.4	5.6
8. Gate-operating Board	unit	4	2	8.0
9. Installation	L.S.	1	-	4.0
10. Others	L.S.	1	-	3.2
Total				72.0

(3) Flood Warning System

The dam breach analysis of the Nam Ngao dam indicates that the flood wave due to a breach damps out around Ban Huai Sai. Taking into consideration the inhabitant condition along the Yuam river, flood warnings (silen) are to be released over upstream of the conjunction of the Yuam and Ngao rivers (Ban Mae Suat - Ban Huai Sai).

Installation cost of flood warning system was roughly estimated 70 million Baht including 5 silen stations and one control equipment (see Fig. 5-40).

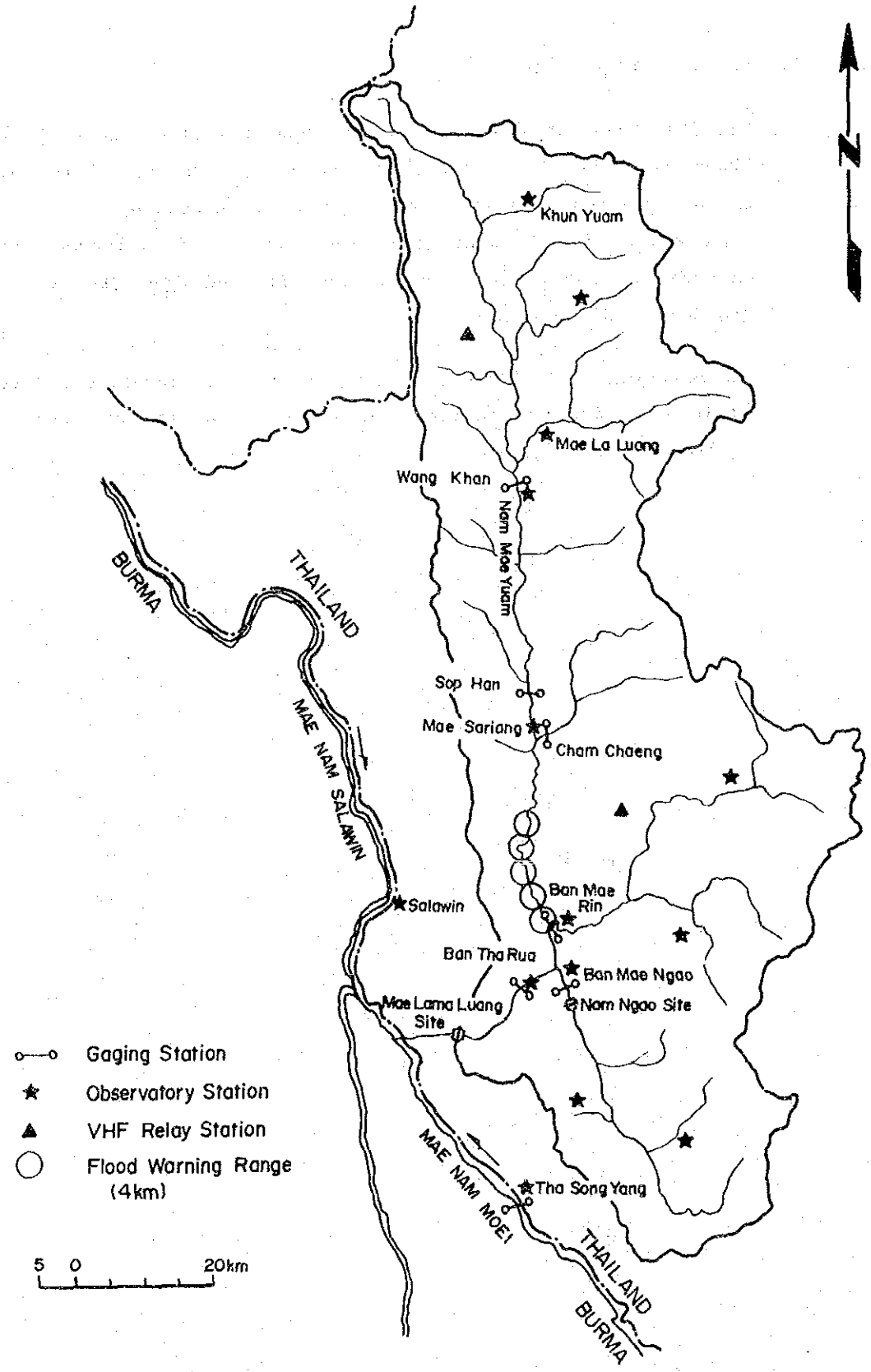

Fig. 5-40 Location Map of Hydrological Forecasting System

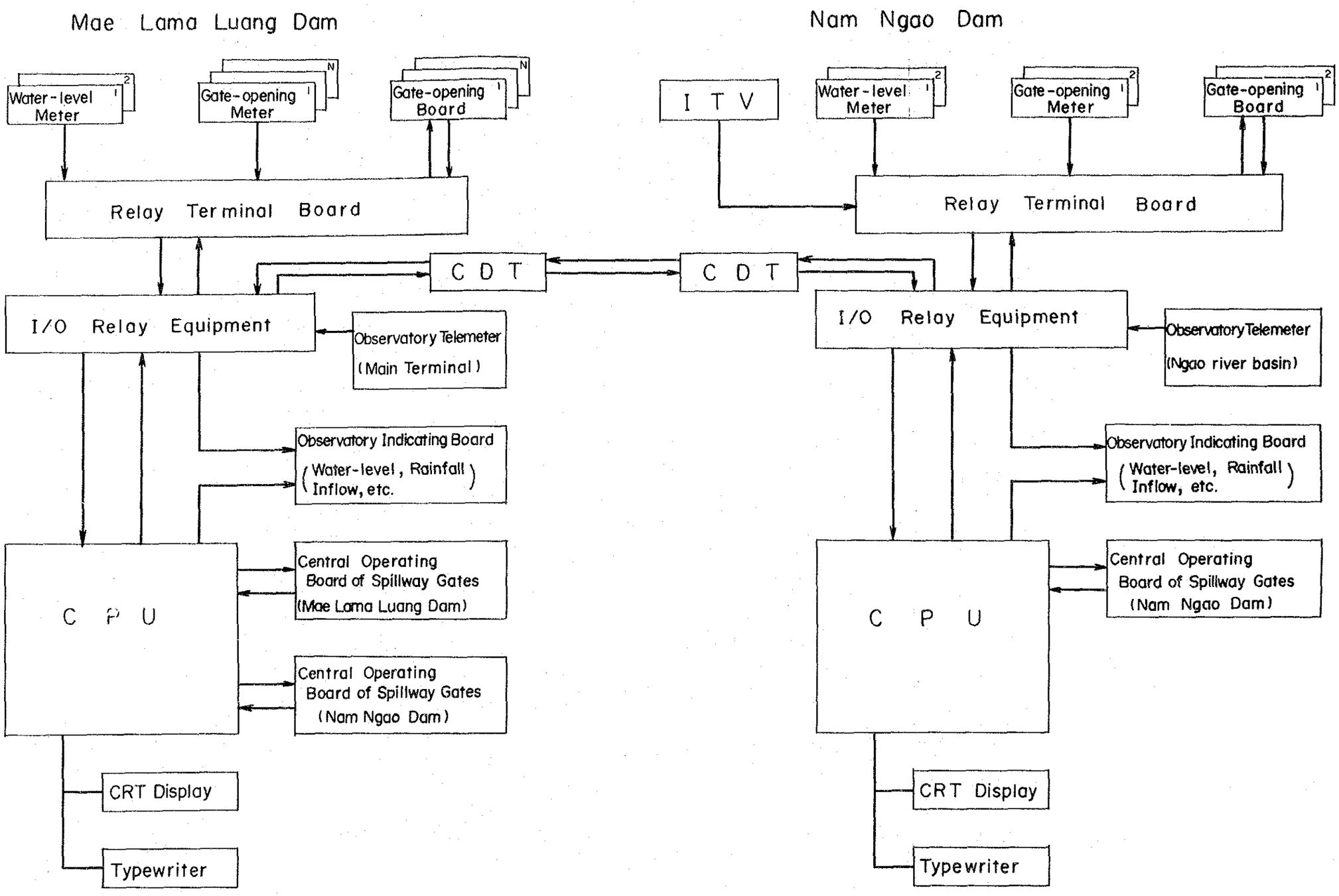

Fig. 5-41 Central Control System of Spillway Gates

CHAPTER 6

GEOLOGY AND CONSTRUCTION MATERIALS

CHAPTER 6 GEOLOGY AND CONSTRUCTION MATERIALS

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CHAPTER 6 GEOLOGY AND CONSTRUCTION MATERIALS

6.1 Regional Geology

6.1.1 Topography

The Yuam river as shown in Fig. 6-1, flows from nearby Khun Yuam at around lat. 19° N and long. 98° E, and flows south for about 120 km meandering through the Mae Sariang basin. Meanwhile, the Ngao river, the largest tributary of the Yuam river rises around lat. 17.40° N and long. 98° E, flows north for about 40 km and joins the Yuam river. The Yuam river turns in direction to the west after joining the Ngao river and flows about 30 km, and then joins the Moei river which forms the border between Thailand and Myanmar.

A basin stretches extensively along the Yuam river from its source down to around a point about 25 km south of Mae Sariang. Further downstream and along the Ngao river, steep valley is predominant.

The catchment area of the Mae Lama Luang dam, about 6,000 km^2 large, has a topography stretching about 30 to 50 km east and west and about 160 km north and south as shown in Fig. 6-1. The west-side boundary of the catchment area faces mountains having a height of 1,000 m or so and stretching straight to the south from Mt. Wi Cho Lo (height 1,056 m). The east-side boundary faces mountains having a height of 1,500 to 1,800 m and stretching south from Mt. Pha Ti Do (1,821 m high).

6.1.2 Geology

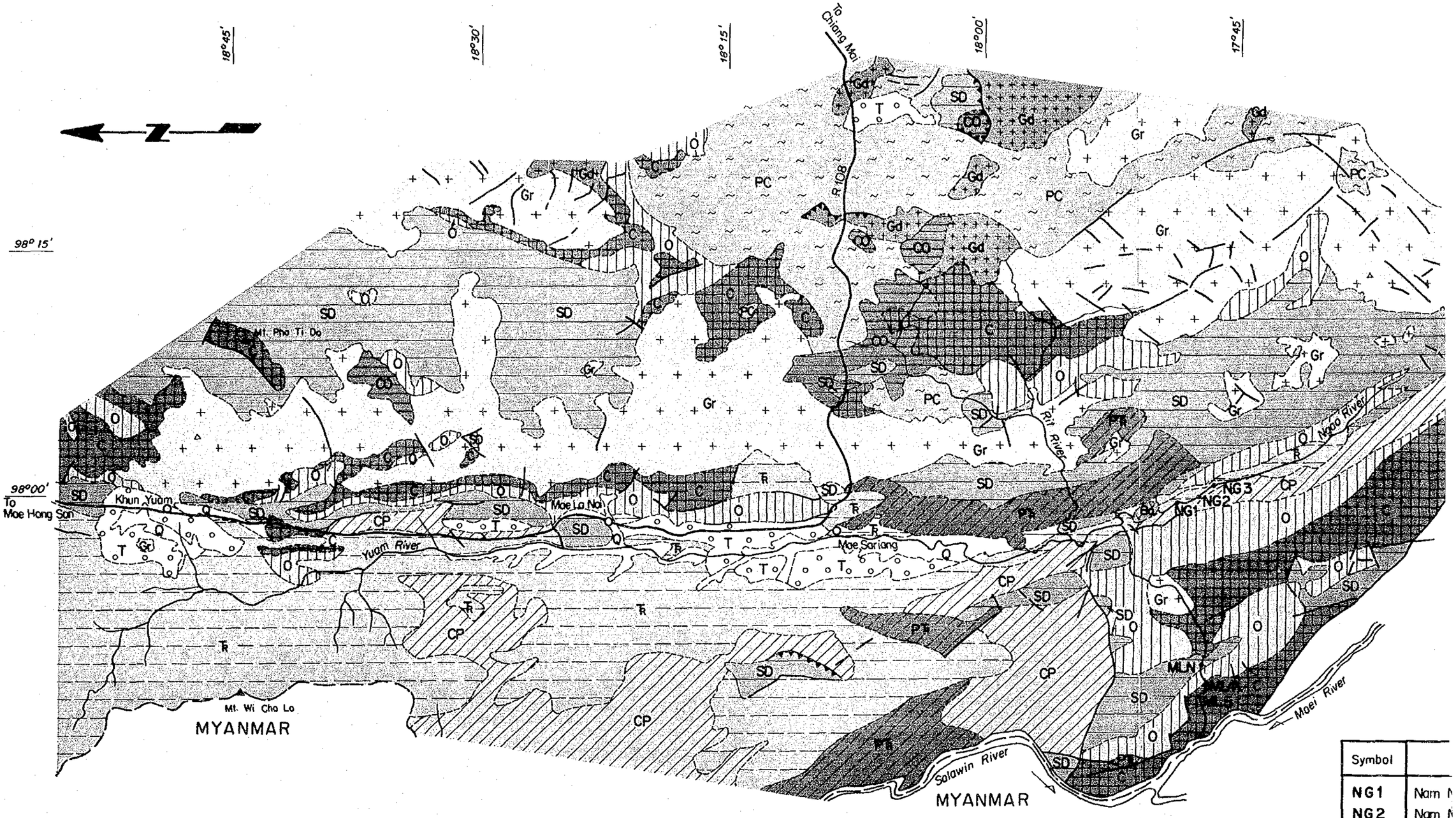
The project area, as shown in Fig. 6-1, consists mainly of Paleozoic and Mesozoic sedimentary rocks and Mesozoic granite.

Paleozoic rocks ranging from Cambrian to Carboniferous period are classified into strata consisting mainly of non-calcareous rocks and Ordovician strata consisting mainly of limestone. The former strata are distributed widely, centering around the southern and eastern part of the project area, and the latter runs north and south in a belt shape within strata consisting mainly of non-calcareous rocks.

Paleozoic rocks ranging from Carboniferous to Permian age and Triassic rocks are composed mainly of non-calcareous rocks, and are distributed in a large part of the northwestern section of the project area.

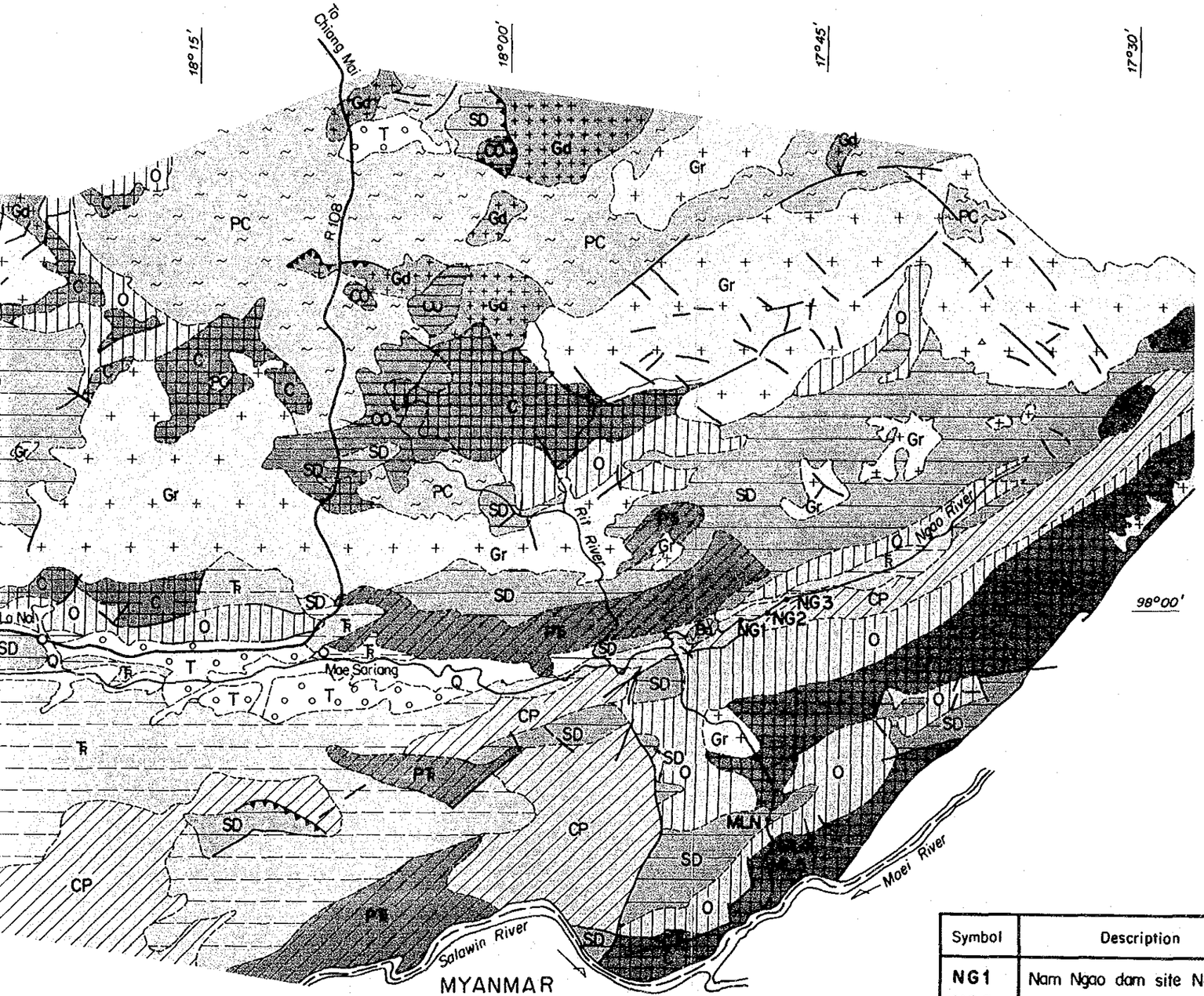
Granite is intruded into Paleozoic rocks in the whole of the eastern section of the project area, and is distributed north and south in a long-stripe rock body 10 km to 20 km wide.

In the part of northern Thailand including the project area, Mesozoic orogenic movement having two phases of latest Triassic to Jurassic phase and Jurassic to Cretaceous phase occurred. The existing geological structure is affected by this orogenic movement, and structures in the north and south or northwest and southeast directions are conspicuous. The project area is also subjected to this effect, so that the strike of strata, the strike of folds and the strike of remarkable faults are mainly in the north and south or northwest and southeast direction.



Symbol	
NG1	Nam N
NG2	Nam N
NG3	Nam N
MLN	Mae La
ML4	Mae La
ML5	Mae La

Note : This map is simplified from Geological Map of Thailand (1/500,000) published by Geological Survey Division Department of Mineral Resources, 1983 Edition.



LEGEND

Cenozoic	Quarternary	Q	Gravel, Sand, Silt, and Clay
	Tertiary	T	Sandstone, Shale, Lignite, and Limestone
Mesozoic	Triassic	R	Sandstone, Limestone, and Conglomerate
Paleozoic	Permian	P	Sandstone, Shale, and Limestone
	Carboniferous	CP	Sandstone, Shale, and Chert
	Devonian Silurian	SD	Quartzite, Phyllite, Schist, Sandstone Shale, and Tuff
	Ordovician	O	Bedded to massive Limestone Argillaceous Limestone
		C	Quartzite, Quartz Schist, Mica Schist and Marble
	Cambrian	C	Sandstone, Quartzite, Phyllite
Precambrian		PC	Gneiss, Amphibolite schist, Calc-silicate rock and Biotite marble
		Ba	Basalt
		Gr	Granite, Granodiorite and Diorite
		Gd	Intrusive complex; Granite and Granodiorite

Geological boundary

Fault Thrust fault

0 — 20 Km

Symbol	Description
NG1	Nam Ngao dam site No.1
NG2	Nam Ngao dam site No.2
NG3	Nam Ngao dam site No.3
MLN	Mae Lama Luang dam site NEA
ML4	Mae Lama Luang dam site No.4
ML5	Mae Lama Luang dam site No.5

s simplified from Geological Map of Thailand (1/500,000) published by
Survey Division Department of Mineral Resources, 1983 Edition.

NAM YUAM RIVER BASIN INTEGRATED HYDROELECTRIC DEVELOPMENT PROJECT

GEOLOGY OF YUAM RIVER BASIN

Fig. 6 - 1

6.2 Geological Investigation Works

The following sites were studied for the project:

(1) Ngao River

1. Nam Ngao dam site No. 1
2. Nam Ngao dam site No. 2
3. Nam Ngao dam site No. 3

(2) Yuam River

1. Mae Lama Luang dam site NEA
2. Mae Lama Luang dam site No. 4
3. Mae Lama Luang dam site No. 5

Of the above sites, a comparative study conducted in advance revealed Nam Ngao dam site No. 2 (for the Ngao river) and Mae Lama Luang dam site No. 5 (for the Yuam river) as the most promising ones. Subsequently these two proposed sites, Nam Ngao dam site No. 2 and Mae Lama Luang dam sites, were investigated geologically from 1985 to 1987.

6.2.1 Nam Ngao Dam

The following surveys were carried out on the Nam Ngao dam site No. 2.

(1) Surface Geological Survey, and Prospecting for Availability of Materials

Survey area	:	The proposed reservoir area and its vicinity along tributary streams, and the dam site and adjacent grounds.
Scale of topographical maps	:	1/5,000 1/1,000

(2) Seismic Prospecting

Survey area	:	Vicinity of dam axis and ridges at Nam Ngao dam site No. 2
Quantity	:	14 lines, 4,565 meters (Refer to Table 6-1.)

(3) Drilling

Survey area	:	Vicinity of dam axis and Nam Ngao dam site No. 2
Quantity of drill holes	:	10 holes, 645.6 meters (Refer to Table 6-1.)
		42 permeability tests and 22 standard penetration tests

(4) Test Pits for Impervious Core Materials

Test pits	:	4 areas, 18 pits
Road cut trenches	:	1 area, 3 trenches
Auger drilling	:	4 areas, 44 holes

Samples were collected for laboratory testing.

(5) Test Pits for Transition (Filter) Materials

Test pits	:	24 pits, 62.8 m

Samples were collected for laboratory testing.

(6) Rock Materials

Test specimens were taken from outcrop at 1 place.

(7) Chemical Analysis of Rocks : 3 samples

(8) Microscopic Observation of Rocks : 6 samples

6.2.2 Mae Lama Luang Dam

The following surveys were carried out at Mae Lama Luang dam site No. 5.

(1) Surface Geological Survey

Survey area : Along the rivers in the proposed reservoir area and its surroundings, from Mae Lama Luang dam site No. 5 to site No. 4

Scale of topographical maps : 1/5,000
1/1,000

(2) Drilling

Survey area : Mae Lama Luang dam site No. 5

Quantity of drill holes : 25 holes, 1,350.3 meters (Refer to Table 6-2.)

190 permeability tests and
16 standard penetration tests

(3) Test Pits for Impervious Core Materials

Test pits : 3 areas, 19 pits

Road cut trench : 1 area, 1 trench

Auger Drilling : 2 areas, 62 holes

Samples were collected for laboratory testing.

(4) Test Pits for Filter Materials

Test pits : 1 area, 35 pits

Samples were collected for laboratory testing.

(5) Rock Materials

Test specimens were taken from outcrops at 4 places.

(6) Chemical Analysis of Rocks : 4 samples

(7) Microscopic Observation of Rocks : 6 samples

Table 6-1 Geological Investigation for Nam Ngao Dam Site

Location		Line No.	Length(m)	Remarks
Left-Bank Side Ridge		S 1	600	
		S 2	200	
Dam Axis	Center	S 3 (1/2)	475	
		〃 (2/2)	450	
	Down-stream	S 4	225	
		S 4 a	200	
		S 4 b	200	
	Up-stream	S 8	330	
		S 9	275	
		S11	110	
Riverbed		S 5	350, 110 } 460	
		S10	110	
Right-Bank Side Ridge		S 6	165	
		S 7	775	
Total		14 Lines	4.565	

Stage	Location	Hole No.	Coordinate		Elevation (m)	Angle from Horizontal	Length (m)	Permeability test	Standard Penetration Test (times)
			Northing	Easting					
Master Plan Study	Right Bank	DR-0	1,967.293	393.859	271.909	90 °	35.0	-	-
		DR-1	1,967.249	393.920	271.250	90 °	90.0	11	-
		DR-2	1,967.208	393.792	223.833	90 °	35.0	-	-
		DR-3	1,967.177	393.669	180.650	90 °	55.0	9	-
	Riverbed	DR-4	1,967.131	393.520	161.050	90 °	90.0	15	-
	Left Bank	DL-1	1,967.084	393.344	220.380	90 °	70.0	7	-
		DL-2	1,967.051	393.228	302.412	90 °	92.0	3	-
	Sub Total (7 Holes)						467.0m	45times	-
Feasibility Study	River Bed	DR-5	1,966.999	393.602	166.110	60°, S70°W	56.2	2	-
	Right Bank	DR-6	1,967.049	393.774	201.725	90 °	60.0	8	1
		DR-7	1,967.108	393.974	279.969	90 °	100.0	10	2
		DR-7A	1,966.965	393.944	258.802	90 °	27.0	-	-
		DR-8	1,967.001	394.033	293.682	90 °	90.0	11	2
	Right Bank side ridge	Q-1	1,966.849	394.538	342.581	90 °	59.4	-	-
	Left Bank	DL-3	1,966.937	393.509	202.043	90 °	75.0	6	2
		DL-4	1,966.910	393.378	254.454	90 °	92.6	5	7
		DL-4A	1,966.808	393.381	223.973	90 °	9.0	-	-
		DL-6	1,966.685	393.017	309.496	90 °	76.4	-	8
	Sub Total (10 Holes)						645.6m	42	22
Total 17 Holes							1042.3m	87	22

Table 6-2 Geological Investigation for Mae Lama Luang Dam Site

Location		Hole No.	coordirnate		Elevation (m)	Angle from Horizontal	Length (m)	Permeability Test (times)	Standard Penetration Test (times)
			Northing	Easting					
Dam	Right Bank	DR-1	1,966.276	372.243	176.99	90°	96	5	–
		DR-1A	1,966.262	372.279	174.27	90°	70	13	–
		DR-2	1,966.218	372.239	133.36	90°	45	6	–
		DR-3	1,966.140	372.259	88.99	90°	40	6	1
		DR-4	1,966.143	372.179	65.88	60° N40E	60	7	–
		DR-5	1,966.225	372.147	120.73	90°	40	6	1
		DR-6	1,966.340	372.328	236.59	90°	50	7	2
		DR-7	1,966.161	372.300	110.30	90°	50	8	–
		DR-8	1,966.053	372.303	72.51	90°	50	8	–
	River-bed	DH-1	1,966.126	372.166	61.93	90°	50.6	8	–
		DH-2	1,966.019	372.284	62.59	90°	45	7	–
	Left Bank	DL-1	1,965.981	372.061	166.49	90°	110	15	–
		DL-2	1,966.047	372.103	126.76	90°	50	6	–
		DL-3	1,966.006	372.172	107.94	90°	45	7	–
		DL-4	1,966.099	372.059	99.28	90°	60	10	1
		DL-5	1,965.936	371.960	201.93	90°	40	10	5
		DL-6	1,965.992	372.112	145.29	90°	50	10	–
		DL-7	1,965.976	372.244	91.43	90°	15	1	–
		DL-7A	1,965.975	372.260	76.03	90°	40	6	–
Spillway		SP-1	1,966.113	371.961	91.78	90°	50	9	4
Powerhouse & Penstock		PH-1	1,966.244	371.998	74.54	90°	50	9	1
		PH-2	1,966.316	372.101	127.24	90°	80	14	1
		DR-9	1,966.272	372.110	105.34	90°	55	7	–
Intake		DI-1	1,966.204	372.341	150.88	90°	56	5	–
Quarry Site		QSB-1	1,965.879	372.751	199.40	90°	52.7	–	–
Total 25 holes							1350.3	190	16

6.3 Site Geology

6.3.1 Nam Ngao Dam

(1) Comparison of Proposed Dam Sites

The location of the alternative dam sites are shown in Fig. 6-2. A comparison of the topographical and geological conditions of Site No. 1, 2 and 3 of the Nam Ngao dam is shown in Table 6-3.

From a topographical viewpoint, the ridge on the right bank at Site No. 1 is eroded and dissected by the stream. The altitude of the ridge top is 260 m, and it is estimated from the weathered condition of the foundation rock, that the high water level is 240 to 250 m at the maximum. Also, the left bank at site No. 3 is eroded by the stream, and the altitude of the ridge top is 280 m, and the high water level is about 270 m at the maximum. The width of the ridge on the left bank at EL.270 m is 70 m. On the other hand, at site No. 2, the width of the ridge at the proposed high water level of EL.270 m is 140 m on the left bank and 150 m on the right bank. Further, either faults or lineaments exist at all gullies eroding the ridge.

From a geological viewpoint, it is presumed from the results of the surface geological survey that at Site No. 1, there is a thick detritus deposit and weathered zone comprising sandstone and an alternation of sandstone and shale. At site No. 3, there is limestone continuously distributed widely in upstream to downstream directions at the right abutment. The limestone was found to contain solution cavities, and it is estimated that it has a high permeability. At site No. 2, the site mainly consists of sandsone and an alternation of sandstone and shale, and limestone distributed partially at the higher part of the right bank. The sandstone and the alternation of sandstone and shale show low permeability. The extent of weathering is great at the higher part of left bank but slight at the river bed and on the right bank.

Judging from these topographical and geological conditions, site No. 2 is considered to be most promising. Accordingly, the discussion is made on Nam Ngao dam site No. 2 as follows, and hereafter the dam site No. 2 is called "the dam site" without the number of "No. 2".

(2) Geology of Reservoir

- General Geology

A geological map of the reservoir area is shown in Fig. 6-2. The reservoir area consists of Paleozoic to Mesozoic rocks and Quaternary terrace and detritus deposits covering the rocks. The Paleozoic to Mesozoic rocks are composed of sandstone, alternation of sandstone and shale, and limestone. These strata generally have strikes in the northwest to southeast directions and are dipped 30° to 60° northeast or southwest.

The sandstone is dark grey to black in color, composed of fine to medium grains and hard. However, at the outcrop, it is discolored due to weathering and covered with deposits. Consequently it is difficult to distinguish the sandstone from the sandstone in the alternation strata. Accordingly in the geological map, the sandstones are incorporated into the alternation.

The alternation of sandstone and shale is composed of fine to medium grained sandstone and, grey to dark grey, hard shale. The rock facies are varied, and there are areas where sandstone is predominant and areas where shale is predominant. The thickness of each stratum varies in a range from 1 cm to 10 m or larger. Part of the sandstone changes to tuffaceous rocks some of which are greyish white, and it is conceivable that this alteration was caused by hydrothermal activity. Also a lot of calcite veins 1 to 5 mm wide were found in the sandstone.

The limestone is greyish white or grey, compact and sound. Outcrops of it are found along the Mae Lui stream on the

upstream of the right bank at the dam site and all over on the right bank at site No. 3. It contains solutions or solution cavities 1 m or so in diameter.

In the Quaternary strata, terrace deposits are distributed on the lower part along the Ngao river, and detritus deposits exist in the middle of the slopes and at the bottom of the stream. The terrace deposits are composed of hard and round to subround gravel 3 to 30 cm in diameter and medium to coarse grain sand. The terrace deposits distribute locally within a height of 10 to 15 m from the existing river bed. The detritus deposits are composed of silt and clay containing an angular to subangular gravel of sandstone and shale, and is classified as reddish brown lateritic soil.

Lineaments in the reservoir along the Ngao river are predominant and have good continuity to the east of the Yuam river.

According to the information in "NAM MAE YUAM Hydroelectric Development Project Feasibility Report" (by JICA, March 1984), a fault corresponding to this lineament is confirmed to the east of the upstream of the Yuam river. It is reported that the fault NNW-SSE strike and almost vertical dip. Further the width of the shear zone is a few meters.

Furthermore, this study revealed that at some of the outcrops along the Ngao river, there are sheared zones 2 m to 3 m in width. Also there are fault sheared zones extending in the form of an echelon in the direction of the river.

The slopes of the reservoir are assumed to be stable, because there is no evidence of landslide or collapse of the unconsolidated materials.

- Karstification

A quantitative chemical analysis of rocks was made to determine the content of carbonate minerals ($CaCo_3$, etc.) in the rocks distributed in the reservoir area. Seven samples of limestone and one sample of calcareous sandstone were

collected. These samples included five samples tested at the time of the master plan stage.

The samples were analyzed for Cao, MgO, SiO_2 and Al_2O_3. The results of analyses are shown in Table 6-4. The limestones (Sample No. 1, 2, 4 and 7) distributed from the right bank to the Mae Lui stream at the dam site contain 62% to 93% of $CaCO_3$ and $CaMg(CO_3)_2$ and 5% to 20% of SiO_2 and Al_2O_3. The limestone has solution cavities 5 to 30 cm in diameter along cracks in it, and many solution cavities are observed in loose sections at the outcrops especially along the Mae Lui stream. The thin limestone layers (Sample No. 6) at the upstream Ngao river bed at the dam site and the limestone (Sample No. 8) widely distributed on the right bank at Nam Ngao dam site No. 3 are composed of 79 to 82% of $CaCO_3$ and $CaMg(CO_3)_2$ and 7% of SiO_2 and Al_2O_3. On the right bank of Nam Ngao dam site No. 3, many solution cavities 10 to 30 cm in width were observed.

The calcareous sandstone (Sample No. 3) in the alternation of sandstone and shale that are widely distributed in the vicinity of the dam site is composed of 13% of $CaCO_3$ and $CaMg(CO_3)_2$ and 82% of SiO_2 and Al_2O_3. No solution cavities were observed.

As described above, the limestone distributed upstream of the right bank of the dam site and the limestone distributed on the right bank of dam site No. 3 have high contents of carbonate mineral contents. Because of this, this limestone does not have strong resistance to solution.

(3) Reservoir Watertightness

The factors relating to reservoir watertightness can be classified into two major categories:

Topographical factors such as a thin ridge, and geological factors such as the formation of a continuous cave. The Nam Ngao reservoir has the characteristics concerned with the following categories.

- Reservoir Watertightness Judged from Topography

As shown in Fig. 6-3 (1-2), topographically, the areas subject to water leakage in the Nam Ngao reservoir are the thin ridge section that extends for about 500 m continuously in a southwest direction from the left dam abutment, and the abutment area on the right bank. The abutment area on the right bank is closely related to the karstic rocks and is therefore discussed in detail in the next paragraph. The width of the thin ridge on the left bank is about 150 m on average at the reservoir high water level of EL.270 m. (See Fig. 6-4(2-3), Section C-C).

The foundation rocks comprising the left ridge consist of alternations of sandstone, shale and calcareous rocks. From a viewpoint of rock characteristics, there is little or no possibility that these foundation rocks will allow solution caves to be formed as will affect reservoir watertightness. According to the results of DL-6 (length: 76.4 m) drilled in the ridge, the weathering (from the ground surface) of the foundation rocks of the ridge has developed conspicuously from the top of the hole (EL.309.4 m) to the bottom of the hole (EL.233 m) to such an extent that the rocks have been so weathered and cracked that it was impossible to set a packer for the permeability test.

On the other hand, the data obtained on February 24, 1989, about 7 months after the completion of the drilled hole indicate that the groundwater level in the hole is 58.8 m (EL.250.6 m) deep from the top of the hole.

Generally, it is extremely difficult to estimate the amount of water leakage after the reservoir has been impounded at a site under such topographical and geological conditions as described above. The most important reason for this is that it is impossible to accurately determine the number and properties of cracks that develop in the foundation rocks.

For instance, if the amount of water leakage is to be calculated on the assumption that the conditions at the dam site

can be roughly calculated using the Darcy's law, the amount of water leakage would be such a level as would not cause any problem in comparison with the amount of inflow into the reservoir and its capacity.

Judging from experience, the watertightness of the reservoir can be ensured by taking foundation treatment to serve impermeability down to the groundwater level. Therefore, a final judgment of the necessity of foundation treatment should be made after a more detailed survey in the next stage. It is concluded at this feasibility study that the ridge at the left bank be treated for impermeability to some extent.

- Reservoir Watertightness Judged from Geology

As shown in Fig. 6-3(1-2), 6-3(2-2) and 6-4(3-3), at an level of EL.270 m or below, on the right bank of the dam, an alternation of sandstone and shale (partially calcareous sandstone) is distributed, and at EL.270 m or higher, karstic limestone is distributed. The topography of the dam abutment on the right bank is such that a ridge extending nearly in the northwest-southeast direction is formed and the width of the ridge at EL.270 m (HWL) along the dam axis is about 150 m. The topography of the right ridge is such that in comparison with the topography on the left bank, the width of the ridge is about the same, but on the right bank, unlike on the left bank, there is no continuous thin ridge extending for as long as about 500 m.

The ridge on the right bank is composed of karstic limestone, and the groundwater level is EL.221 m (DR-1, Feb. 24, '89) to EL.227 m (DR-7, Feb. 24, '89). These drilling cores are all strongly weathered above the groundwater level, and there are many areas where it is not possible to recover core samples or where there are many solution cracks.

In the vicinity of the reservoir high water level of EL.270 m at the abutment on the right bank of the dam, the topography

is such that a thin ridge is formed and the ridge is composed of karstic limestone, with conspicuous karstic erosion observed from the ground surface down to EL.220 to 230 m. Consequently, the area near this location is a cause of anxiety regarding water leakage both topographically and geologically.

The karstic limestone found at the abutment on the right bank of the dam is distributed for about 1.8 km on the right bank of the Mae Lui stream, which flows into the right bank upstream of the dam site. In the geological survey concerning the limestone, no other work was done except for the drilling of one short drill hole (Q-1, 59.4 m) and a surface geological survey. In Q-1, a noticeable karstic erosion has developed over the whole depth, and besides no groundwater has been confirmed even at the bottom of the hole (EL. about 283 m). At the outcrops on the ground surface, there are cavities in places, but no large-scale karstic erosion such as sinkholes has been found thus far.

On the other hand, the limestone is dipped toward the downstream side of the reservoir on the whole. (See Section EE, FF in Fig. 6-4(3-3)). Therefore, if the groundwater level is low in this large limestone mass as in the case of the abutment on the right bank and a conspicuous karstic erosion has developed down to EL.220 to 230 m, there is a possibility that water will leak out of the reservoir through this limestone mass. However, the limestone is covered with a formation comprising non-karstic rocks as can be seen in Fig. 6-4. Hence, it is considered that there will be no leakage even if reservoir water should penetrate into the limestone. Therefore it will eventually fill the reservoir up to the full level so long as the limestone is not exposed in any place outside the reservoir.

At this stage, no data have been collected that give a definite indication of the probability of leakage. As stated above, we recognize the necessity of foundation treatment to ensure reservoir watertightness at the right abutment and

ridge from both topographical and geological viewpoints. As to the limestone mass along the Mae Lui stream, however, a final conclusion should be reached after a detailed geological survey is made in the future, and at this moment, we would acknowledge the necessity for planning foundation treatment if we are to be on the safe side.

(4) Seismic Prospecting

Seismic prospecting (refraction method) was carried out by the EGAT for the purpose of exploring the geological conditions in the vicinity of the dam foundation and ridges of both banks.

- Quantity of Seismic Prospecting

The quantity of seismic prospecting was fourteen prospecting lines for a total length of 4,565 m as shown in Fig. 6-3(2-2). The details are shown in Table 6-1.

- Outline of Seismic Prospecting Method

Seismic prospecting is an exploration technique consising of artificially generating elastic waves near the ground surface, measuring the elastic waves at the ground surface, and determining the underground geological conditions through analysis of the measurement data.

This prospecting method is frequently used as one of the most effective techniques for geotechnical engineering investigations.

A conceptual diagram of the seismic prospecting method is shown below.

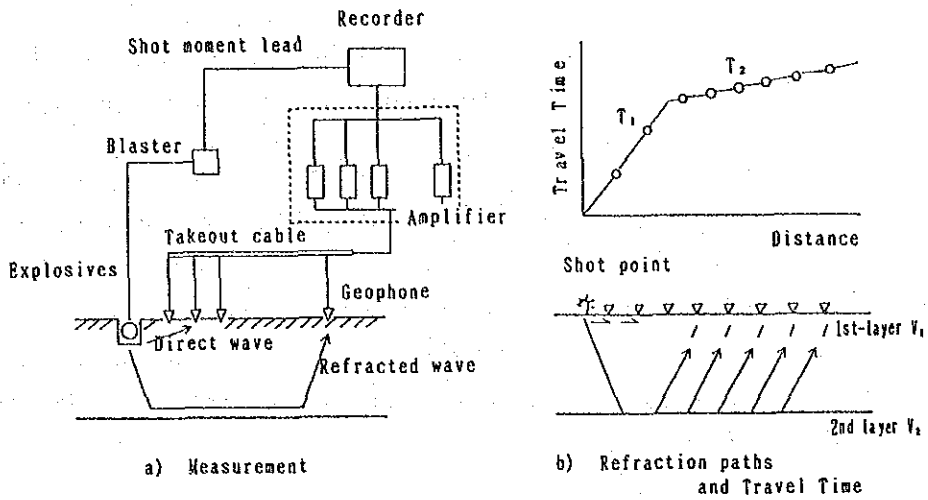


Diagram of Seismic Prospecting Method

- Measurement Method

Instruments

Measurement was made with the instruments listed in the Table below.

List of Seismic Prospecting Instruments

Name	Specification	Note
Amplifier	No. of channels: 12	SIE Model RS-4AC U.S.A.
Recorder	No. of channels: 12	
Geophone	Frequency 4.5 Hz	Mark Products, U.S.A.
Blaster Source	Explosive	Minimum delay time detonater
Takeout Cable	12 take outs	Mark Products, U.S.A.

- Analysis Method

There are various methods for analysis used in seismic prospecting, but in this study Hagiwara's analysis method and

its expanded version, which have been most widely used in engineering geologic investigations have been adopted.

However, in the event that a low-velocity layer exists underground, the depth of that layer cannot be determined with the above-mentioned method which regards underground structure as discrete velocity-layers. In such case, analysis of the travel-time curve was made assuming the underground structure was not discrete velocity-layers but a Mirage layer.

Details of Hagiwara's method are presented in Appendix.

- Results

A time-distance curve and seismic profiles obtained by the analysis, and an example of the curve are shown in Fig. 6-5. All of the curves of the lines are attached in Appendix. As a result of the analysis, the subterranean structure at the investigation site was divided into the following three velocity layers. The velocity layers at the respective prospecting lines are described below.

o First layer: Vp = 0.3 - 0.6 km/sec

It may be considered that this layer corresponds to detritus deposit, top soil, and strongly weathered rock. The thickness of this layer was about 5 - 10 m at the part of ridge and slope and about 0 - 5 m at the lower part of the slope.

o Second layer: Vp = 0.8 - 1.8 km/sec

It may be considered that this layer corresponds to the weathered zone of the foundation rocks.

o Third layer: Vp = 1.5 - 2.0 km/sec (left bank),
2.5 - 4.0 km/sec (left to right banks)

This layer is the lowest layer of the foundation basement rocks and it may be considered that it corresponds to fresh and sound foundation rock on the right bank and to the weak zone due to weathering, alterated or fractured rock on the left bank.

- Estimation of Distribution and Properties of Foundation Rock

o It is estimated that the thickness of the deposit and weathered rock is thicker in the left bank than in the right bank of the dam site, the thickness of which is 30 - 40 m on the left bank and about 20 m on the right bank.

o The thickness of the weathered zone of the foundation rock and recent river deposit was about 15 m.

o Judging from the result of S_1 profile line along the ridge on the left bank particularly, the foundation velocity as can be seen in other profile lines could not be detected and the velocity layer of about 1.5 - 1.8 km/sec was distributed to the deep portion. Thus, it may be assumed that the weathered zone is thick or there is a deteriorated zone, such as a fault altered zone, etc.

o With regard to the line S_3 (2/2) on the right bank, it is clear that the low velocity zone exists from EL. 180 m to 190 m.

(5) Geology of Dam Site

- Topography

A terrace covering an area of about 200 m in width develops on the right bank. The upper part, following from the terrace, forms a slope of 20° to 30°. As for the left bank, there is no terrace, but a slope of 30° to 35°. The right abutment of the dam site has a gully cutting in parallel to the Ngao river, and the ridge on the right bank side is thin,

extending in the NNW-SSE direction. The left abutment has a gully cutting from the downstream of the site. The gully changes direction from N-S to ENE-WSW and a thin ridge is formed N-S direction at the dam axis.

- Geology

The geological map of the dam site is shown in Fig. 6-3, and a geological profile in Fig. 6-4. Geology of the dam site consists chiefly of an alternation of sandstone and shale, and limestone. Terrace, river deposit and detritus deposit, covering the foundation rocks, are distributed.

The alternation of sandstone and shale is distributed widely over the dam site except in the limestone distribution area from the higher part on the right bank of the dam site to its upstream of right ridge. The strike of the alternation is N 10° to 50°W in parallel with the downstream direction of the Ngao river and it is dipped 50° to 80° northeast or southwest, due to the effect of a fold having an axis running in the direction of the strike. The alternation strata is dark grey or black and hard in its fresh sections, and has a 50 cm to 1 m or so interval of crack. The depth of the weathered surface layer is shallow on the right bank of the dam site and at the river bed, but there is a thick weathered zone having a maximum thickness of 40 m on the left bank. This weathered zone is widely found on the ridge section on the left bank that extends from the abutment of the dam, and weathering is observed down to a depth of 31 m in DL-6. There are many calcite veins 1 mm to 5 mm in width and discoloration in the alternation strata. These phenomena suggest that the alternation strata may have suffered a hydrothermal alteration.

The limestone is distributed from the higher part of the right bank of the dam site to the ridge section that extends to the Mae Lui stream. The limestone contacts with the alternation strata in the form of faults or conformities. The boundary of the right bank forms a fault which has a

strike N20° W and contacts many places in the surroundings of the Mae Lui stream in the form of faults. As mentioned in 6.3.1 (2), the results of the chemical analysis indicate that the limestone has a high content of carbonate minerals and contains solution cavities. The rocks themselves are hard, and the interval of the cracks is 1 to 2 m.

Sheared zones are distributed in the river bed along the Ngao river. Also, the boundary area between the alternation of sandstone and shale and limestone that is distributed on the right bank is a fault. On the other hand, several faults are distributed in the direction along the Mae Lui stream and in the direction crossing the stream nearly at right angles.

The conspicuous fold is found on the left bank of the dam site and has an axis that is parallel to the Ngao river.

Terrace deposits are widely distributed in the lower part of the right bank, and also locally on the lower part of the slope of the left bank which is covered with detritus deposits. The terrace deposits consist of sand and hard round gravel 1 to 10 cm in diameter.

The detritus deposits are distributed on the gentle slopes of the upstream left bank of the dam site and on the slopes of the right bank. The detritus deposits are composed of gravel with soil that derived from alternation of sandstone and shale.

- Groundwater Level

Paragraph (3), "Reservoir Watertightness", describes the groundwater level in detail. The results of observation of the groundwater level in the drilled holes, are shown in Table 6-5.

- Observations

Judging from the geological conditions of the ground surface, drilled holes including results of permeability test and rock

test, Nam Ngao dam site is evaluated from a viewpoint of engineering geology as follows.

- The rocks distributed at the dam site have a sufficient durability to serve as the foundation of the proposed dam. However, the weathered zone on the higher part of the left bank and at the fault on the river bed need foundation treatment.

- The permeability tests indicate that the sandstone and shale, except in the weathered zone, have a low permeability (0 - 5 Lu).

- The groundwater tables in the ridges of the left bank and of the area just upstream of the right bank are lower than the reservoir water level of 270 m, and these areas have a high permeability. The watertightness can be improved by foundation treatment.

(6) Geology of Main Structure Sites

From the result of seismic prospecting and drilling carried out in the vicinity of the main structure sites, the geology of these sites is estimated as described below;

- Intake and Headrace Tunnel

Drilled hole DR-7A is located just downstream of the intake. The site is composed of an alternation of sandstone and shale. The weathered zone of surface layer is 10 m thick, and the portion from 10 m to 16 m is fresh and hard but has been cracked to a great extent. The velocities from seismic prospecting in the weathered and fractured zone are 1.0 to 1.2 km/sec.

On the other hand, the headrace tunnel is presumed to pass through the alternation of sandstone and shale and limestone. In the area of the headrace tunnel route, on the whole fresh and massive rock foundation is distributed, but locally some sheared zones be distributed.

- Powerhouse

Drill holes of DR-3 and DR-4 are located upstream of the powerhouse. The site is composed of an alternation of sandstone and shale which forms massive, fresh and sound rock. The weathered zone of the surface layer is 5 m or less in thickness.

- Spillway

The site consists of an alternation of sandstone and shale. The thickness of weathered zone of the surface layer is 19 m at DL-1 and is in a fragmented condition down to a depth of 12.50 m. On the other hand, the thickness of the weathered zone of the surface layer at DL-4 is 41 m and is in a strongly fragmented condition down to a depth of 23 m. The geology of the section beneath the weathered zone is hard but has many cracks and the velocity from seismic prospecting is 3 km/sec or higher.

At the projected sites for the above main structures, there are places with relatively thick weathered zone and locally deteriorated areas, but there is no serious problem in view of geotechnical engineering.

6.3.2 Mae Lama Luang Dam

(1) Comparison of Proposed Dam Sites

The location of the alternative dam sites are shown in Fig. 6-6. A topographical and geological comparison of sites NEA, No. 4 and No. 5 is shown in Table 6-6.

From a geological viewpoint, the geological conditions of these sites are almost the same.

As for the selection of the dam site, site No. 5 has been chosen in view of the locations, workability and economics of the dam and the main structures as discussed in Chapter 8 "Development Plans". Accordingly, the discussion is made on

Mae Lama Luang dam site No. 5, and hereafter the dam site No. 5 is called "the dam site" without the No. 5.

(2) Geology of the Reservoir

- General Geology

A geological map of the reservoir area is shown in Fig. 6-6 and 6-7. The reservoir area is composed of Paleozoic to Mesozoic rocks intruded by granite and basalt, Tertiary sediments and Alluvial deposits.

Paleozoic rock is widely distributed in the reservoir area, while the Mesozoic rock is being distributed along the upper reaches of Yuam river which lies in nearly N-S direction. The Paleozoic rock is composed of quartzite, quartz schist, phyllite, argillaceous limestone and sandstone locally calcareous. The mesozoic rock is composed of alternation of sandstone and shale, shale, calcareous sandstone and thin bedded limestone. These rocks trend north-south or northwest-southeast, and dip 30° to 60° east or west.

The quartzite and schist are light grey or pinkish light grey, fine grained and hard. These rocks are, as shown in Fig. 6-7, distributed forming an anticlinal structure with an axis of fold in nearly the north and south direction along the La Po Kra stream and the La Cho Kra stream and surroudings of dam sites Nos. 4 and 5.

The alternation of sandstone and shale is composed of grey to dark grey shale and grey, fine to medium grained sandstone. This strata changes widely in rock facies. The faces of the strata are composed almost of shale layer to the sandstone layer in 50 cm - 1 m width interbedded with shale of the thickness 1 cm or less. This alternation is distributed to the east of the La Cho Kra stream, repeatedly in belts in a north and south direction.

Shale and calcareous shale are grey to black and hard. They are banded in an interval of a few cm to 20 cm.

Calcareous sandstone has a facies in which grey argillaceous laminae are interbedded in the light-brown arenaceous part.

The limestone is of two types; dark grey or light grey massive limestone and a dark grey to grey or light brown one in which laminae are developed. Solution cavities 5 cm to 40 cm wide are frequently observed along the joint planes in the massive limestone. On the other hand, limestone in which the laminae are well developed has a few solution cavities of 1 cm or less in diameter.

Tertiary sediments are distributed on both bank of the Yuam river upstream from the end of the backwater of the reservoir. They consist of shale, sandstone and conglomerate which are poorly consolidated. These Tertiary sediments can be easily distinguished from Paleozoic and Mesozoic rocks by aerophoto interpretation due to their topographic features.

The alluvial deposits are mainly in the form of a terrace deposit along the Yuam river, consisting of silt, sand and gravel. The alluvial deposits have developed widely along the Yuam river upstream from the end of backwater of the reservoir.

Granite is intruded into the paleozaic to Mesozoic rocks in the form of a small rock mass about 6 km long and about 3.5 km wide along the Yuam river in the downstream of Ban Tha Rua.

Basalt is distributed in the form of a small rock body about 3.5 km and about 1.2 km wide about 1 km upstream from the point where the Yuam river joins the Ngao river.

Folds observed in the reservoir area have their axis in a north-northwest and south-southeast direction and have a wave length of 2 to 4 km.

A remarkable fault is seen on the east side of the upper reaches of the Yuam river. This fault has NNW-SSE strike and an almost vertical dip. The width of sheared zone is a few

meters. According to the results of aerophoto interpretation and surface geological survey, this fault is considered to extend south along the right bank of the Ngao river.

- Karstification

A chemical analysis of rocks was made to determine the carbonate ($CaCo_3$, etc.) content of the rocks distributed in the vicinity of the reservoir. One sample of sandstone, calcareous sandstone, calcareous schist and limestone was collected.

Analysis was made for CaO, MgO, SiO_2 and Al_2O_3. Result of analysis is shown in Table 6-7.

The sandstone and calcareous sandstone were sampled from DR-6, located on the higher part of the right bank of the dam site (See Fig. 6-8(2-2)). The sandstone of sample No. 10 contains 1% or less of $CaCO_3$ and $CaMg(CO_3)_2$, 87% of SiO_2 and 5% of Al_2O_3. The calcareous sandstone of sample No. 9 contains 25% $CaCO_3$ and $CaMg(CO_3)_2$, 62% SiO_2 and 4% Al_2O_3. On the other hand, the record taken at the time of drilling indicates that there is a total length of about 10 m of solution cavities centered around depths of 32 m and 40 m.

The calcareous schist of sample No. 11 contains 33% $CaCO_3$ and $CaMg(CO_3)_2$, 47% SiO_2 and 4% Al_2O_3. No solution cavities were observed in the drilled hole cores and in outcrops.

The limestone of sample No.12 contains 69% $CaCO_3$ and $CaMg(CO_3)_2$, 14% SiO_2 and 3% Al_2O_3. On the outcrops, a slight erosion was observed on the surface of the limestone.

As mentioned above, the limestone distributed on the higher part of the right bank has a high content of carbonate minerals. However, other rocks contain little carbonate mineral.

According to aerophoto interpretations, a karst topography is seen on the plateau of over 500 to 600 m in height which is in the limestone distribution area.

(3) Reservoir Watertightness

There is no evidence topographically subject to leakage in the Mae Lama Luang reservoir.

On the other hand, as shown in Fig. 6-9(1-2), quartz schist and calcareous schist are distributed in the lower part of the abutment on the right bank, but the formation changes to calcareous sandstone and limestone toward the top. The groundwater level at DR-1A on the right bank is EL. 140 m (December 26, '88). The section above the groundwater level shows high permeability with a coefficient of permeability of 10^{-3} to 10^{-4} cm/sec. The strike of the strata from the dam right bank to the upstream reservoir side is N20° to 50°W and it is dipped 40° to 55° NE.

In view of the facts that the strata dips toward the mountain side and the strike is in the direction of crossing the dam, that the groundwater level is low in comparison with the high water level (165 m) and the permeability is high in this area, and that the existence of solution cavities has been confirmed at DR-6, it is judged that foundation treatment for reservoir watertightness is required on the right bank.

(4) Geology of Dam Site

- Topography

The area around the dam sites (No. 5) as shown in Fig. 6-6, forms mountains generally ranging in altitude from 500 to 600 m, extending from the northwest to the southeast, and the Yuam river flows almost perpendicularly to the line connecting those mountains.

The river bed near the dam site is almost 65 m in altitude, and the river banks frequently form a V-shaped steep slope with an angle of more than 50 degrees.

The terrace deposit and river deposit near the river bed are distributed in a narrow range with a width of about 50 m, not presenting any clear terraces.

- Geology

The geological map and profile of the dam site are shown in Figs. 6-8 and 6-9. The area around the dam site consists mainly of sedimentary rocks of the Paleozoic era, and Quaternary deposits overlie at parts of the river bed and slopes.

The sedimentary rocks forming the foundation are Cambrian to Ordovican. The strata trend generally N-S or NNW-SSE, and dip irregularly 25° to 70° east or west under the influence of folds whose trends are the same as the direction of the strata.

The sedimentary rocks distributed at the dam sites are primarily classified into two types. One is non-calcareous rock consisting of quartz schist interbedded with calcareous schist and quartzite. The other is calcareous rock consisting of limestone, calcareous sandstone, and limestone and interbedded sandstone. The non-calcareous rock is exposed in lower parts, that is, below EL.250 m on the right bank and below EL.225 m on the left bank. In the case of site No. 4 located 1 km upstream from the dam site, it is exposed below EL.175 m on the right bank and throughout the abutment on the left bank.

The calcareous rock crops out at higher parts in such a way that it overlies the non-calcareous rock.

The results of the chemical analysis of rocks and the microscopic observation (see Appendix) revealed the following fact. The most of non-calcareous rock consists of schist which is rich in calcareous matter. The calcareous rock contains little carbonate mineral. Considering above, the rock distributed in vicinity of the dam site changes from calcareous schist or quartzite in the low altitude to limestone distributed in the high altitude.

The surface layer of the bed rock typically presents as follows. The rocks outcropping on the river bed are hard and

massive. However, rocks slightly softened by weathering in the trenches on the dam axis slope and in the gully just downstream of the site are observed. Moreover of the drill holes on the dam axis, DR-1 on the right bank (EL.177 m at ground surface) has about a 30 m weathered zone, and DL-1 on the left bank (EL.167 m at ground surface) has a weathered zone of about 35 m in thickness, in addition the permeability of these zones is considerably high.

The detritus deposit covering the bed rock is widely distributed over the downstream gully on the right bank and the gentle slopes downstream of the dam site. The deposit is also distributed in the lower part along the downstream gully on the left bank and over the dam axis on the left bank. The deposit consists of clay sand silt or clay mixed with hard pebbles and rock fragments. River deposit and terrace deposit are sparsely distributed along the Yuam river. It is difficult to distinguish these two layers due to the fact that both consist primarily of medium to coarse sand and contain some pebbles, and that the terraces are not fully developed. Because of sporadic outcrops of bed rocks along the river bed, the river deposit is generally not considered thick, but a layer of 10 m has been confirmed in drill holes (DR-4, DH-1).

- Groundwater Level

The result of measurement of the groundwater level in the drilled holes are shown in Table 6-8.

- Observations

Judging from the geological conditions of the ground surface, drilled holes including permeability test and rock test, the Mae Lama Luang dam site is evaluated from a viewpoint of engineering geology as follows.

- On the whole, the bed rocks distributed in the dam site are fresh, massive and sound and have sufficient durability to serve as the foundation of the proposed dam.

- The foundation rock except for the weathered zone and the limestone distributed at the higher part of right bank, shows a low permeability (lower than 3 Lu) and sufficient watertightness.

- The weathered rock distributed in the foundation area of the proposed impervious core should be removed.

- The watertightness of the right bank should be improved such that the groundwater table becomes the same level as the reservoir water level or permeability is lower than 5 Lu. Treatment such as grouting is possible to improve the foundation.

As stated above, it is judged that the Mae Lama Luang dam site has no geological problem.

(5) Geology of Main Structure Sites

The location of drill holes is shown in Fig. 6-8(2-2) and 6-9(2-2).

- Intake, Headrace Tunnel and Penstock

DI-1 is located just downstream of the intake. The site is composed of sandy limestone, calcareous schist and limestone. The detritus deposits and weathered zone of the surface layer is 2 m to 3 m thick, and the section beneath it down to 16 m is fresh and hard, and has some cracks. DR-1, DR-1A and DR-9 are located in the area through which the headrace tunnel and penstock pass. The geology of the site is about the same as the intake and is generally fresh and hard. At a depth of 57 to 87 m in DR-1, there are many cracks due to shearing.

- Powerhouse

PH-1 is located at the powerhouse site. The geology is composed of quartz schist and quartzite, which are generally sound and fresh. The thickness of the detritus deposits and weathered rocks in the surface layer is 5 m. At a depth of 5 to 8 m, there are weathered and fragmented rocks, and at a

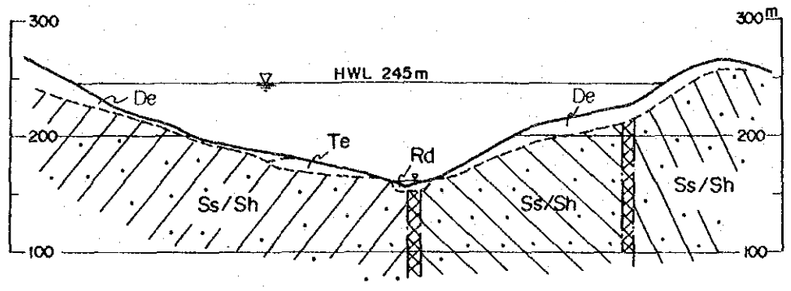
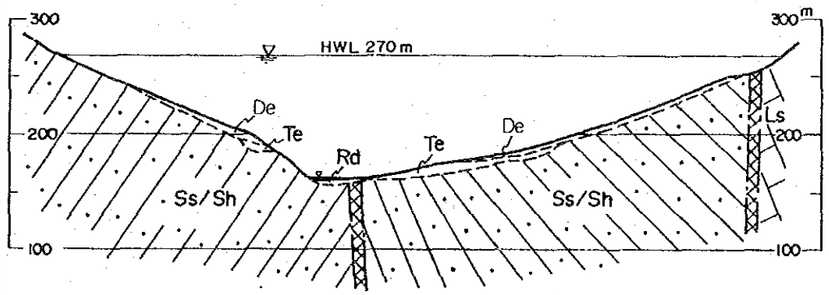
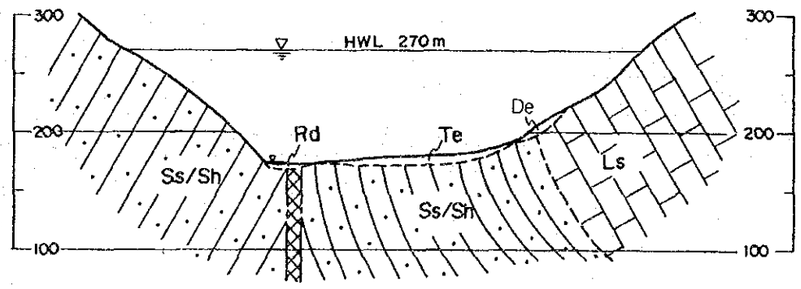
depth of more than 8 m, the rocks have few cracks and are hard. Also it is presumed that the overburden on the slope behind the powerhouse is about 5 m thick.

- Spillway

DL-1 is located at the projected site of the spillway gate, and SP-1 at the projected site for the spillway chute. The geology consists mainly of quartz schist and calcareous schist. At DL-1 the thickness of the weathered zone of the surface layer is large, and the rock is fragmented down to 36.3 m. Also, at SP-1 the weathered zone is fragmented down to 13.60 m. In the sections beneath these weathered zones, the geology is generally fresh and hard.

At the projected sites for the main structures, there is a thick weathered zone upstream of the spillway, but there is no other geo-technical engineering problem.

Table. 6-3 COMPARISON OF NAM NGAO DAM SITES

Damsite	※1 Location	Topography: Width of Ridge Left	Topography: Width of Ridge Right	Topography: ※2 Profile	Geology: Foundation Rocks	Geology: Weathering, Faulting, Alteration	Geology: Overburden	Remarks
No. 1	7.5km	270m (EL. 245m)	120m (EL. 245m)		・Sandstone ・Alternation of sandstone and shale	・Weathered zone of both banks are thick ・Some lineaments (fault) are developed along the river	・Thick	
No. 2	9 km	140m (EL. 270m)	150m (EL. 270m)		・Sandstone ・Alternation of Sandstone and shale ・Limestone	・Weathered zone of left bank is thick ・Lineaments across the both banks	・Rather thick	Geological investigation work finished to date (1) Seismic prospecting explo - ration 14 lines. — 4,565m (2) Drilling 17 holes 1,042.3 m
No. 3	11.5km	70m (EL. 270m)	—		・Alternation of sandstone and shale ・Limestone	・Karstic limestone is distributed on right abutment ・Terrace deposit are widely dis - tributed on lower part of right bank	・Rather thick	

※1 Distance from confluence of the Yuam and Ngao river
※2 De:Topsoil, Residual soil and Detritus deposits Rd:River deposit Te:Terrace deposit Ls:Limestone
ss/sh:Alternation of sandstone and shale :shearedzone

Table 6-4 Quantitative Chemical Analysis of Rock (Nam Ngao Dam)

Sample No.	1/ Locality	Rock Type	Result of Analysis	2/ Result of Norm Calculation	3/ Result of Norm Calculation	Remarks
			Composition % (Wt)	Composition % (Wt)	Composition % (Wt)	
1	NG2 Drill Hole DR-1 (Depth:18.85 - 18.95m)	Limestone	CaO 45.10 MgO 2.58 SiO_2 9.93 Al_2O_3 2.40 Total 60.01	CaO 80.49 MgO 5.40 SiO_2 9.93 Al_2O_3 2.40 Total 98.22	CaO 74.09 $CaMg(CO_3)_2$ 11.80 SiO_2 9.93 Al_2O_3 2.40 Total 98.22	
2	NG2 Drill Hole DR-1 (Depth:83.2 - 83.25m)	Limestone	CaO 51.89 MgO 0.47 SiO_2 3.37 Al_2O_3 1.30 Total 57.03	CaO 92.60 MgO 0.98 SiO_2 3.37 Al_2O_3 1.30 Total 98.25	$CaCO_3$ 91.43 $CaMg(CO_3)_2$ 2.15 SiO_2 3.37 Al_2O_3 1.30 Total 98.25	
3	NG2 Drill Hole DR-3 (Depth:45.9 - 46.0 m)	Calcareous Sandstone	CaO 4.11 MgO 2.85 SiO_2 69.25 Al_2O_3 12.32 Total 88.53	CaO 7.33 MgO 5.96 SiO_2 69.25 Al_2O_3 12.32 Total 94.86	$CaCO_3$ 0.26 $CaMg(CO_3)_2$ 13.03 SiO_2 69.25 Al_2O_3 12.32 Total 94.86	
4	NG2 Drill Hole DR-7 (Depth:53.0 - 53.15m)	Limestone	CaO 34.00 MgO 0.91 SiO_2 15.00 Al_2O_3 5.12 Total 55.03	CaO 60.08 MgO 1.90 SiO_2 15.00 Al_2O_3 5.12 Total 82.10	$CaCO_3$ 57.82 $CaMg(CO_3)_2$ 4.16 SiO_2 15.00 Al_2O_3 5.12 Total 82.10	Solution cavities are rare
5	NG2 Drill Hole DR-2 (Depth:75.2 - 75.3 m)	Argillaceous Band	CaO 18.41 MgO 1.34 SiO_2 53.53 Al_2O_3 6.19 Total 79.47	CaO 32.85 MgO 2.80 SiO_2 53.53 Al_2O_3 6.19 Total 95.37	$CaCO_3$ 29.52 $CaMg(CO_3)_2$ 6.13 SiO_2 53.53 Al_2O_3 6.19 Total 95.37	Argillaceous band in limestone
6	NG2 Right Bank Upstream of Dam axis	Limestone	CaO 38.29 MgO 0.91 SiO_2 26.96 Al_2O_3 1.86 Total 68.02	CaO 68.33 MgO 1.90 SiO_2 26.96 Al_2O_3 1.86 Total 99.05	$CaCO_3$ 66.07 $CaMg(CO_3)_2$ 4.16 SiO_2 26.96 Al_2O_3 1.86 Total 99.05	
7	NG2 Right Bank Upstream of Dam axis (Mae Lui stream)	Limestone	CaO 43.80 MgO 0.48 SiO_2 5.01 Al_2O_3 1.51 Total 50.80	CaO 78.17 MgO 1.00 SiO_2 5.01 Al_2O_3 1.51 Total 85.69	$CaCO_3$ 76.97 $CaMg(CO_3)_2$ 2.20 SiO_2 5.01 Al_2O_3 1.51 Total 85.69	Solution cavities are observid.
8	NG2 Right Bank Upstream of Dam axis	Limestone	CaO 43.40 MgO 2.07 SiO_2 4.79 Al_2O_3 0.93 Total 51.19	CaO 77.46 MgO 4.33 SiO_2 4.79 Al_2O_3 0.93 Total 87.51	$CaCO_3$ 72.32 $CaMg(CO_3)_2$ 9.47 SiO_2 4.79 Al_2O_3 0.93 Total 87.51	Solution cavities are observid.

1/ NG2; Nam Ngao dam site No.2 NG3; Nam Ngao dam site No.3

2/ All Cao are calculated as $CaCO_3$ and all Mgo are calculated as $MgCO_3$

3/ All Cao are calculated as $CaMg(CO_3)_2$ and remaining CaO are calculated as $CaCO_3$

Table 6-5 Groundwater Level of Nam Ngao Dam Site

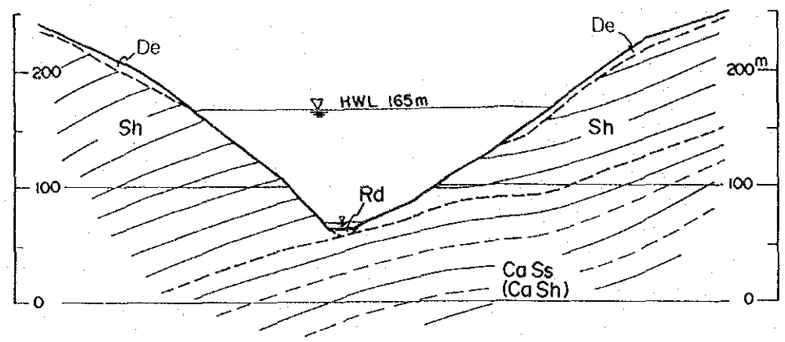
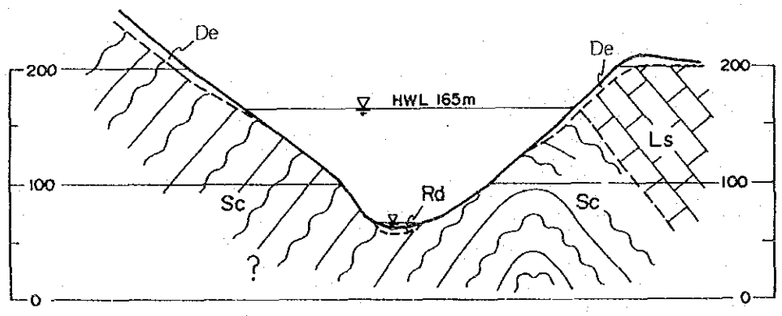
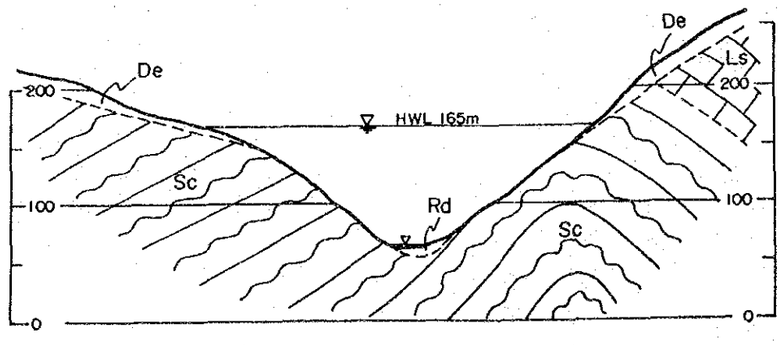
(a) Right Bank

Hole No.	Elevation (m)	Angle from Horizontal	Length (m)	Groundwater Level(m) Depth/Elevation	
				Nov. 20, 1988	Nov. 20, 1988
DR-0	271.906	90°	35.0	16.00 / 255.91	16.00 / 255.91
DR-1	271.250	90°	90.0	52.40 / 218.85	52.70 / 218.55
DR-2	223.833	90°	35.0	10.50 / 213.33	11.20 / 212.63
DR-3	180.650	90°	55.0	9.00 / 171.65	5.10 / 175.55
DR-4	161.050	90°	90.0	2.00 / 159.05	Can not be measured —
DR-5	201.725	90°	56.2	4.30 / 161 81	5.10 / 160.51
DR-6	279.969	60.S90.W	60.0	17.00 / 184.73	17.95 / 183.78
DR-7	258.802	90°	100.0	50.70 / 229.27	52.20 / 227.77
DR-7A	293.682	90°	27.0	No Water —	No Water —
DR-8	293.682	90°	90.0	14.00 / 279.68	17.65 / 276.03
Q -1	342.581	90°	59.0	No Water —	No Water —

(b) Left Bank

DL-1	220.380	90°	70.0	19.20 / 201.18	19.30 / 201.08
DL-2	302.412	90°	92.0	No Water —	No Water —
DL-3	202.043	90°	75.0	30.60 / 171.44	31.30 / 170.74
DL-4	254.454	90°	92.6	34.85 / 219.60	36.00 / 218.45
DL-4A	223.973	90°	9.0	No Water —	No Water —
DL-6	309.496	90°	76.4	56.50 / 253.00	58.80 / 250.70

Table. 6-6 COMPARISON OF MAE LAMA LUANG DAM SITES

Damsite	*1 Location	Topography Profile *2	Geology: Foundation Rocks	Geology: Weathering, Faulting, Alteration	Geology: Overburden	Remarks
NEA	8.5km		• Shale • Calcareous Sand-stone, Calcareous Shale, • Limestone (upper part of left bank)	• Two faults extend across the river • Soluble limestone is distributed from upstream to downstream on upper part of left bank	• Thin	Geological investigation work finished to date (1) Drilling 11holes 745.5 m
No. 4	6 km		• Calcareous Schist • Quartz Schist • Quartzite • Sandy Limestone • Limestone	• Weathered zone is thin.	• Thin	
No. 5	5 km		• Calcareous Schist • Quartz Schist, • Quartzite, • Calcareous Sand-stone	• Strongly weather-ed zones are distributed on upper part of both banks	• Rather thick, especially at upper part of both banks	Geological investigation work finished to date (1) Drilling 25holes 1350.3m

※1 Distance from confluence of the Yuam and Moei river
※2 De:Topsoil, Residual soil and Detritus deposit Rd:River deposit Te:Terrace deposit Ls:Limestone
Sh:shale Ss:Sandstone Sc:Schist, Quartzite, etc

Table 6-7 Quantitative Chemical Analysis of Rock (Mae Lama Luang Dam)

Sample No.	1/ Locality	Rock Name	Result of Analysis	2/ Result of Norm Calculation	3/ Result of Norm Calculation	Remarks
			Composition % (Wt)	Composition % (Wt)	Composition % (Wt)	
9	NY5 Drill Hole DR-6 (Depth:32.10 - 32.20m)	Calcareous Sandstone	CaO 10.20 MgO 3.16 SiO_2 62.30 Al_2O_3 3.87 Total 79.53	$CaCO_3$ 18.20 $MgCO_3$ 6.61 SiO_2 62.30 Al_2O_3 3.87 Total 90.98	$CaCO_3$ 10.35 $CaMg(CO_3)_2$ 14.46 SiO_2 62.30 Al_2O_3 3.87 Total 90.98	
10	NY5 Drill Hole DR-6 (Depth:39.65 - 39.85m)	Sandstone	CaO 0.20 MgO 0.19 SiO_2 87.10 Al_2O_3 5.10 Total 92.59	$CaCO_3$ 0.36 $MgCO_3$ 0.40 SiO_2 87.10 Al_2O_3 5.10 Total 92.96	$CaCO_3$ - $CaMg(CO_3)_2$ 0.76 SiO_2 87.10 Al_2O_3 5.10 Total 92.96	
11	NY5 Drill Hole DL-5 (Depth:27.75 - 27.85m)	Calcareous Schist	CaO 12.30 MgO 5.44 SiO_2 47.20 Al_2O_3 4.36 Total 69.30	$CaCO_3$ 21.95 $MgCO_3$ 11.38 SiO_2 47.20 Al_2O_3 4.36 Total 84.89	$CaCO_3$ 8.44 $CaMg(CO_3)_2$ 24.89 SiO_2 47.20 Al_2O_3 4.36 Total 84.89	
12	NY5 Right Bank Downstream of Dam axis	Limestone	CaO 37.40 MgO 1.22 SiO_2 14.10 Al_2O_3 2.86 Total 55.58	$CaCO_3$ 66.75 $MgCO_3$ 2.55 SiO_2 14.10 Al_2O_3 2.86 Total 86.26	$CaCO_3$ 63.72 $CaMg(CO_3)_2$ 5.58 SiO_2 14.10 Al_2O_3 2.86 Total 86.26	

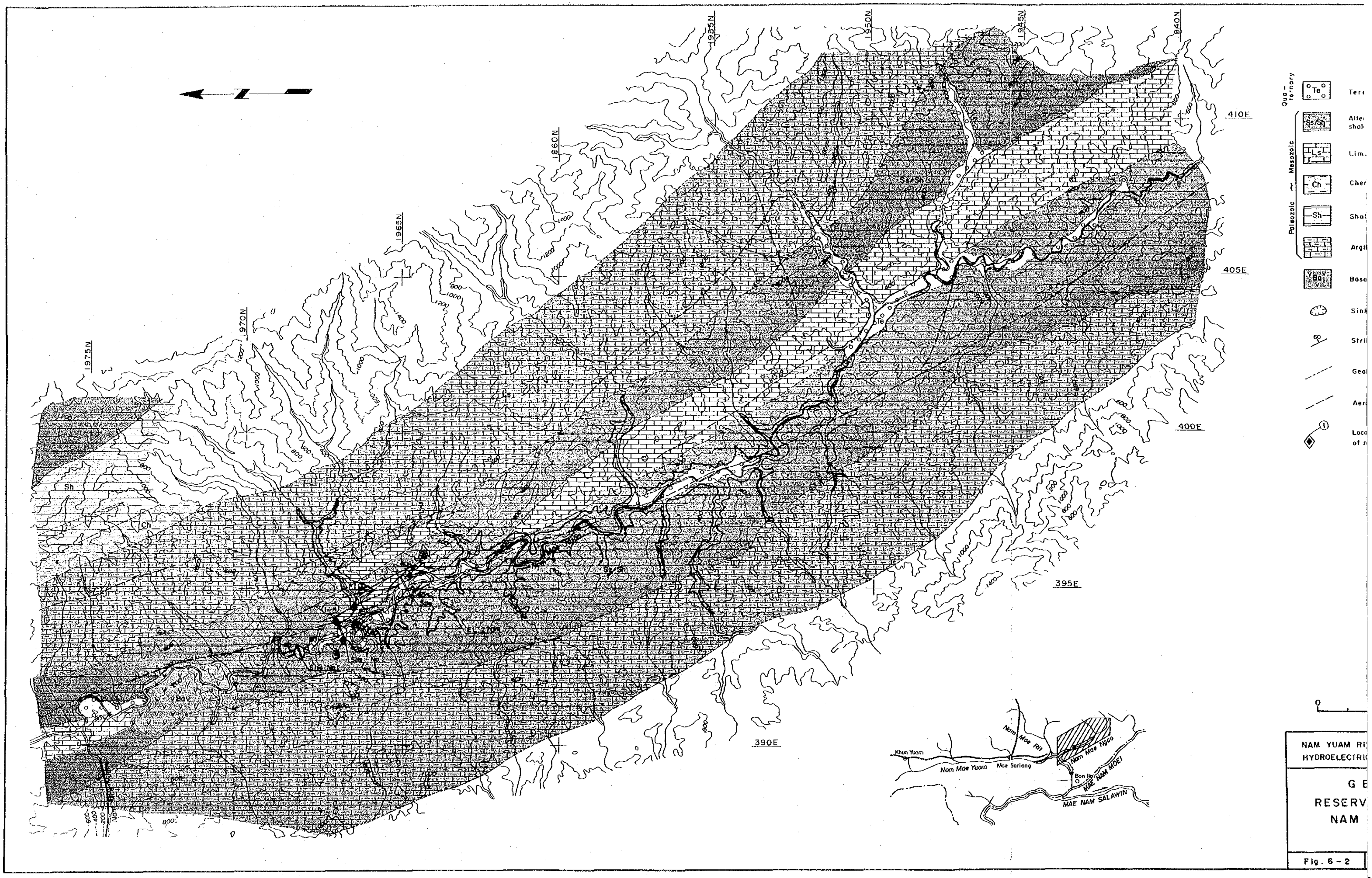
1/ NY5; Mae Lama Luang dam site No.5

2/ All CaO are calculated as $CaCO_3$ and all MgO are calculated as $MgCO_3$

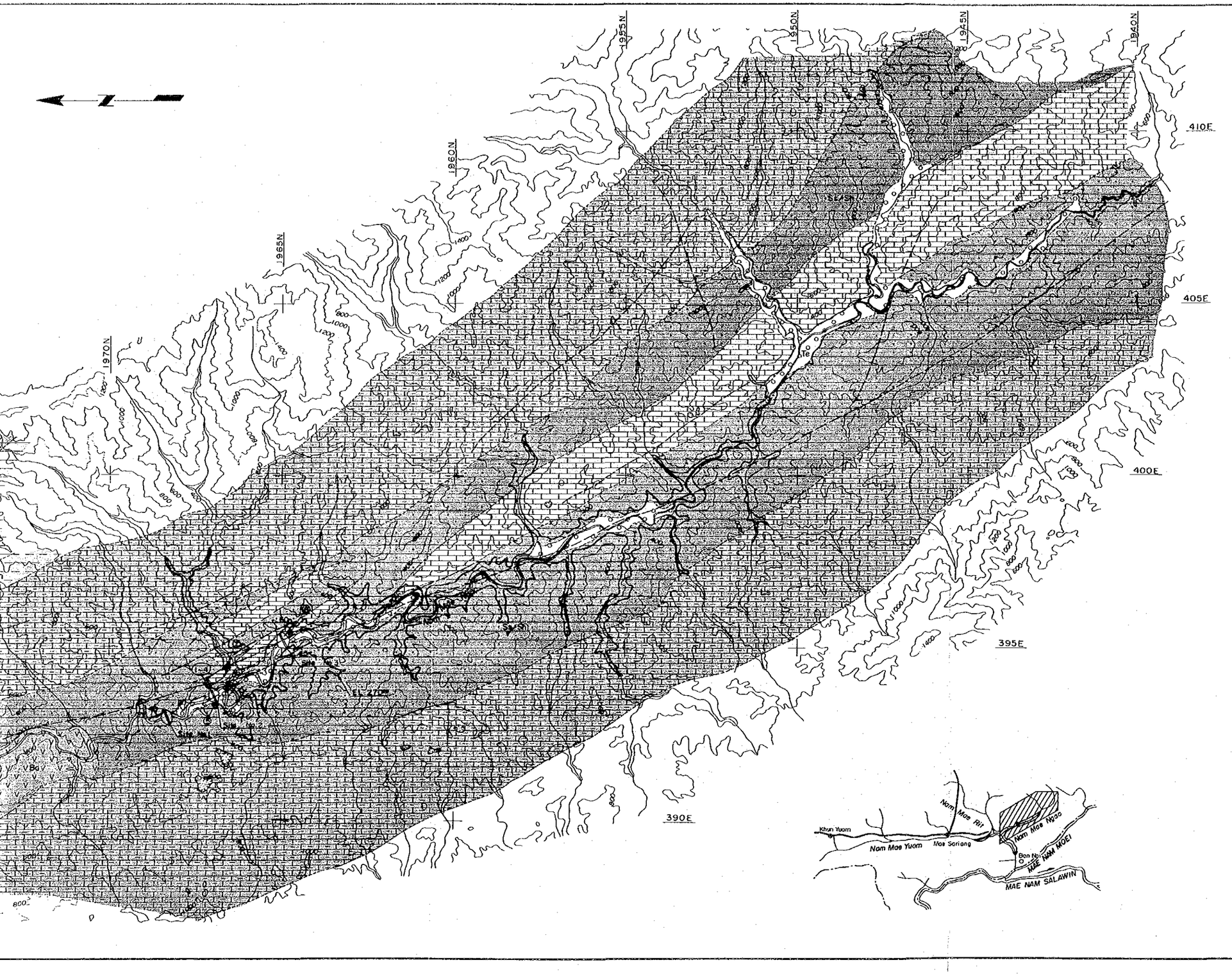
3/ All MgO are calculated as $CaMg(CO_3)_2$ and remaining CaO are calculated as $CaCO_3$

Table 6-8 Groundwater Level of Mae Lama Luang Dam Site

Hole No.	Elevation (m)	Angle from Horizontal	Length (m)	Groundwater Level(m) Depth/Elevation	
				Nov. 21, 1988	Feb. 21, 1981
DR-1	176.99	90°	96.0	——	51.50 / 125.49
DR-1A	174.27	90°	70.0	——	44.00 / 130.27
DR-2	133.36	90°	45.0	——	21.00 / 112.36
DR-3	88.99	90°	40.0	20.55 / 68.44	17.00 / 71.99
DR-5	120.73	90°	40.0	36.40 / 84.33	39.00 / 81.73
DR-6	236.59	90°	50.0	No Water	No Water
DR-7	110.30	90°	50.0	——	24.00 / 86.30
DR-8	72.51	90°	50.0	——	0 / 72.51
DL-1	166.49	90°	110.0	47.05 / 119.44	47.00 / 119.49
DL-2	126.76	90°	50.0	26.89 / 99.87	28.80 / 97.96
DL-3	107.94	90°	45.0	16.80 / 91.14	23.70 / 84.24
DL-4	99.28	90°	60.0	21.70 / 77.58	21.65 / 77.63
DL-5	201.93	90°	40.0	34.90 / 167.03	35.05 / 166.88
DL-6	145.29	90°	50.0	/	41.5 / 104.24
DL-7A	76.03	90°	40.0	/	0 / 76.03
SP-1	91.73	90°	50.0	12.00 / 79.73	12.30 / 79.43
PH-1	74.54	90°	50.0	4.90 / 69.64	27.47 / 47.07
PH-2	127.24	90°	80.0	25.20 / 102.04	5.40 / 121.84



1975N
1970N
1965N
1960N
1955N
1950N
1945N
1940N
410E
405E
400E
395E
390E
Sh
Ch
Ss/Sh
Te
Ls
Ba
Qua-ternary
Paleozoic ~ Mesozoic
Khun Yuam
Nam Mae Yuam
Mae Sariang
Nam Mae Rit
Nam Mae Ngao
MAE NAM MOEI
MAE NAM SALAWIN
NAM YUAM RI
HYDROELECTRI
G E
RESERV
NAM
Fig. 6-2



LEGEND

- Quaternary: Te — Terrace deposit
- Paleozoic ~ Mesozoic:
  - Ss/Sh — Alternation of sandstone and shale
  - Ls — Limestone
  - Ch — Chert
  - Sh — Shale
  - Argillaceous limestone
- Ba — Basalt
- Sink hole
- 60 — Strike and dip of strata
- Geologic boundary
- Aerophoto lineament
- 1 — Locality for chemical analysis of rock samples

0 5km

NAM YUAM RIVER BASIN INTEGRATED HYDROELECTRIC DEVELOPMENT PROJECT

GEOLOGY RESERVOIR AREA OF NAM NGAO DAM PLAN

Fig. 6 - 2