GOVERNMENT OF MALAYSIA

# NATIONAL WATER RESOURCES STUDY, MALAYSIA
# PERLIS-KEDAH-PULAU PINANG
# REGIONAL WATER RESOURCES STUDY
## PART 1

## VOL. 9
## ANNEX

J. ENGINEERING GEOLOGY
K. CONSTRUCTION MATERIAL
L. PROPOSED DAM PROJECTS

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FEBRUARY 1984

JAPAN INTERNATIONAL COOPERATION AGENCY

NATIONAL WATER RESOURCES STUDY, MALAYSIA
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PART 1

## LIST OF VOLUMES

# ABBREVIATIONS

(1) Organization/Plan

| | | |
|---|---|---|
| 4MP | : | Fourth Malaysia Plan |
| DID (JPT) | : | Drainage and Irrigation Department |
| EPU | : | Economic Planning Unit |
| FELCRA | : | Federal Land Consolidation and Rehabilitation Authority |
| FELDA | : | Federal Land Development Authority |
| GSD | : | Geological Survey Department |
| JICA | : | Japan International Cooperation Agency |
| MADA | : | Muda Agricultural Development Authority |
| NEB (LIN) | : | National Electricity Board |
| NWRS | : | National Water Resources Study |
| PWD (JKR) | : | Public Works Department |
| RISDA | : | Rubber Industry Small-Holders Development Authority |
| WHO | : | World Health Organization |

(2) Others

| | | |
|---|---|---|
| B | : | Benefit |
| BOD | : | Biochemical Oxygen Demand |
| C | : | Cost |
| COD | : | Chemical Oxygen Demand |
| D&I | : | Domestic and Industrial |
| dia. | : | Diameter |
| EIRR | : | Economic Internal Rate of Return |
| El. | : | Elevation Above Mean Sea Level |
| Eq. | : | Equation |
| Fig. | : | Figure |
| GDP | : | Gross Domestic Product |
| GNP | : | Gross National Product |
| H | : | Height, or Water Head |
| NHWL | : | Normal High Water Level |
| O&M | : | Operation and Maintenance |
| Q | : | Discharge |
| Ref. | : | Reference |
| SS | : | Suspended Solid |

# ABBREVIATIONS OF MEASUREMENT

## Length

mm = millimeter
cm = centimeter
m = meter
km = kilometer
ft = foot
yd = yard

## Area

$cm^2$ = square centimeter
$m^2$ = square meter
ha = hectare
$km^2$ = square kilometer

## Volume

$cm^3$ = cubic centimeter
l = lit = liter
kl = kiloliter
$m^3$ = cubic meter
gal. = gallon

## Weight

mg = milligram
g = gram
kg = kilogram
ton = metric ton
lb = pound

## Time

s = second
min = minute
h = hour
d = day
y = year

## Electrical Measures

V = Volt
A = Ampere
Hz = Hertz (cycle)
W = Watt
kW = Kilowatt
MW = Megawatt
GW = Gigawatt

## Other Measures

% = percent
PS = horsepower
° = degree
' = minute
" = second
°C = degree in centigrade
$10^3$ = thousand
$10^6$ = million
$10^9$ = billion (milliard)

## Derived Measures

$m^3/s$ = cubic meter per second
cusec = cubic feet per second
mgd = million gallon per day
kWh = kilowatt hour
MWh = Megawatt hour
GWh = Gigawatt hour
kWh/y = kilowatt hour per year
kVA = kilovolt ampere
BTU = British thermal unit
psi = pound per square inch

## Money

M$ = Malaysian ringgit
US$ = US dollar
¥ = Japanese Yen

# CONVERSION FACTORS

| | From Metric System | To Metric System |
|---|---|---|
| Length | 1 cm = 0.394 inch<br>1 m = 3.28 ft = 1.094 yd<br>1 km = 0.621 mile | 1 inch = 2.54 cm<br>1 ft = 30.48 cm<br>1 yd = 91.44 cm<br>1 mile = 1.609 km |
| Area | 1 $cm^2$ = 0.155 sq.in<br>1 $m^2$ = 10.76 sq.ft<br>1 ha = 2.471 acres<br>k $km^2$ = 0.386 sq.mile | 1 sq.ft = 0.0929 $m^2$<br>1 sq.yd = 0.835 $m^2$<br>1 acre = 0.4047 ha<br>1 sq.mile = 2.59 $km^2$ |
| Volume | 1 $cm^3$ = 0.0610 cu.in<br>1 lit = 0.220 gal.(imp.)<br>1 kl = 6.29 barrels<br>1 $m^3$ = 35.3 cu.ft<br>$10^6$ $m^3$ = 811 acre-ft | 1 cu.ft = 28.32 lit<br>1 cu.yd = 0.765 $m^3$<br>1 gal.(imp.) = 4.55 lit<br>1 gal.(US) = 3.79 lit<br>1 acre-ft = 1,233.5 $m^3$ |
| Weight | 1 g = 0.0353 ounce<br>1 kg = 2.20 lb<br>1 ton = 0.984 long ton<br>= 1.102 short ton | 1 ounce = 28.35 g<br>1 lb = 0.4536 kg<br>1 long ton = 1.016 ton<br>1 short ton = 0.907 ton |
| Energy | 1 kWh = 3,413 BTU | 1 BTU = 0.293 Wh |
| Temperature | °C = (°F - 32)·5/9 | °F = 1.8°C + 32 |
| Derived Measures | 1 $m^3/s$ = 35.3 cusec<br>1 $kg/cm^2$ = 14.2 psi<br>1 ton/ha = 891 lb/acre<br>$10^6$ $m^3$ = 810.7 acre-ft<br>1 $m^3/s$ = 19.0 mgd | 1 cusec = 0.0283 $m^3/s$<br>1 psi = 0.703 $kg/cm^2$<br>1 lb/acre = 1.12 kg/ha<br>1 acre-ft = 1,233.5 $m^3$<br>1 mgd = 0.0526 $m^3/s$ |
| Local Measures | 1 lit = 0.220 gantang<br>1 kg = 1.65 kati<br>1 ton = 16.5 pikul | 1 gantang = 4.55 lit<br>1 kati = 0.606 kg<br>1 pikul = 60.6 kg |

# *ANNEX J*

# *ENGINEERING GEOLOGY*

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# 1. INTRODUCTION

As a part of the Perlis-Kedah-Pulau Pinang Regional Water Resources Study, a series of geological investigations was performed from December 1982 to March 1983.

Other than the study of regional geology, stress was put upon the field geological investigation of six contemplated dam schemes as follows:

- Badak Temin dam on the Temin river in the Kedah river basin,
- Durian dam on the Durian river in the Kedah river basin,
- Sari dam on the Sari river in the Kedah river basin,
- Tawar Muda dam on the Muda river main stream,
- Beris dam on the Beris river in the Muda river basin, and
- Rui dam on the Rui river, a tributary of the Perak river.

The field geological investigation comprised surface geological mappings of the dam and reservoir area and core drillings for 950 m in total length with standard penetration tests and permeability tests.

These investigations give rough picture of geotechnical situations of those dam schemes as a basis for the project study in the preliminary stage. More detailed investigations are yet to be performed in the coming stages of feasibility study and detailed design.

## 2. GENERAL GEOLOGY

Peninsular Malaysia is situated on a stable cratonic block of Sunda Shelf and is composed mainly of Palaeozoic and early Mesozoic sedimentary rocks and intrusive granite masses. Its topographic and geologic structures are largely controlled by the north-northwesterly trend of fold mountain system that is outstandingly represented by the Main Range, the cordillera of the peninsula.

The area of Perlis-Kedah-Pulau Pinang, as well as north Perak which is also subject to the study for water diversion scheme to Kedah State, is located in the western side of the Main Range.

The Main Range in its proto-type was formed by up-rising of an extensive Silurian marine sedimentary basin in the period of orogenesis in late Silurain to early Devonian, thereby dividing the western marine sedimentary basin from the eastern counterpart since that time. While granite intrusions and replacements in the orogenesis after late Carboniferous built up the present Main Range which is largely composed of granitic rocks, fractions of the Silurian sediments have remained widely scattered in and around the Main Range.

The above complex of Silurian sediments and intrusive granites is extensively developed in the zone around the eastern border of Kedah State, and stretches its branch across the middle and southern parts of Kedah up to the coastal region. The island of Pinang is entirely composed of granite.

The older sedimentary facies of Cambro-Ordovician are located as local patches in Mt. Jerai in Kedah and in the ridge northwest of Kangar.

Well developed post-Main Range sediments in this area are:

(a) a part of dominantly argillaceous Sungai Petani Formation in the Muda river basin (though main part of this formation is believed to be formed in Silurian);

(b) areno-argillaceous Kubang Pasu and Singa Formation and Chuping limestone of Carboniferous to Triassic which are wide-spread in Perlis and north Kedah; and

(c) areno-argillaceous and rudaceous rocks of Triassic Semanggol Formation developed in the Muda river basin and the upper Kedah river basin.

Local patches of Tertiary continental sediments of Bukit Arang Coal Beds, comprising semi-consolidated gravels, sand and clay, are located in the vicinity of the border line to Thailand. Alluvial deposits consisting of unconsolidated particles of various size cover the coastal plain widely.

Terrain of the hilly and mountainous regions are generally covered by residual soil, the product of decomposition of bed rocks, which is often clayey and reddish brown coloured while some are silty to sandy and variegated. Intensive lateritization is rarely observed.

Dominant north-northwesterly or north-south trend of geological structure is represented in the orientation of axes of folding and tilting of strata, or general strike of bedding planes, and in some of faults. Regional faults trend dominantly northwesterly and subordinately northeasterly, and are believed to be for the most part sinistral wrench faults. Local foldings and deviation from the general trend of strikes of bedding planes are common in the vicinity of the intrusive granites. Hydrothermal alterations and low grade metamorphism are locally observed in the contact zones with granites.

(1) Perlis river basin

The Perlis river basin, 790 $km^2$ in area, is located in the northernmost part of the region, occupying nearly 90% of Perlis State. The western watershed of the basin is 150 m to 550 m high limestone ridge of Ordovician Setul Formation, trending north to south. The northern watershed runs along a chain of high ridges and saddles where the ground height varies from El. 120 to 725 m. Both the western and the northern watersheds form the border of Malaysia and Thailand. The eastern watershed between the Perlis and the Kedah river basins is lower than El. 100 m but for some isolated hills of limestone. In the south, the basin is bordered for the most parts by low hills in the Quaternary plain. The basin opens to Melaka Strait in southwest of Kangar.

The dark grey Ordovician Setul limestone on the western watershed forms a stretch of solid ridge, to which the Quaternary deposit abuts from east in the lower reaches of the basin. In the upper reaches, the Setul limestone is separated by north-southerly faults along the eastern foot of the ridge from areno-argillaceous sedimentary facies and limestones of the upper Devonian to Triassic series, which are widely developed in the upper Perlis river basin. The Chuping Limestone of this series, which is dark coloured, crystalline and occasionally with solution cavities, is well exposed in the central part of the basin, forming prominent Monadnocks at places. It is reported that the limestone tends to thin eastward replaced by areno-argillaceous sedimentary rocks. The shales and sandstones of Kubang Pasu and Singa Formation are wide-spread in the northern half of the Perlis river basin. A local patch of Tertiary deposits of semi-consolidated gravels, sand and clay is located in the northeastern part of the Basin.

The outstanding structural trend is north-south, as represented by general strikes of bedding planes and faults. Northwesterly fault group of the later age are also recorded for the Setul limestone ridge.

The southern part of the basin is extensively covered with thick alluvial deposits.

(2) Kedah river basin

The Kedah river basin, 3,695 $km^2$ in area, covers the northern part of Kedah State. Its northern watershed cum main source of the river is a 90 km long mountain chain along the border of Malaysia and Thailand which is studded with peaks of El. 300 to 780 m, while its western watershed is the low hills shared by the Perlis river basin. In the east and the southeast the Kedah river basin is separated from the Muda river basin by mountain ranges with 200 m to 600 m of ground height. The southern watershed which divides the Merbok river basin is Mt. Jerai (El. 120 m) and other low hills. The Kedah river pours into Melaka Strait at 7.5 km west of Alor Setar.

To the northern part of the basin stretched out from the adjacent Perlis river basin is the upper Devonian to Triassic Kubang Pasu and Singa Formation which is composed of areno-argillaceous sedimentary rocks and covers wide area around Jitra (including the contemplated Badak Temin dam site). Further to the east it is covered unconformably by Mesozoic sediments of siltstones, mudstones, shales and sandstones which are extensively developed from the upper reaches of Padang Terap river (including the contemplated Durian and Sari dam sites) to the eastern divide of the basin. Much difference does not appear from geotechnical viewpoint between these two rock facies.

The southern parts of the basin is composed largely of older formations, i.e. the predominantly argillaceous facies of Silurian, schists and quartzites of Cambrian in Mt. Jerai, etc. Intrusive granites are exposed in places.

The geological structure shows north-southerly trend in general. Bedding planes dip commonly eastward with only local exceptions of folding around the intrusive granites.

Alluvial deposit forms a 10 to 15 km wide belt along the coast. Quaternary terrace deposits are well developed in wide open valleys up to the middle reaches of the basin.

(3) Muda river basin

The Muda river basin, 4,300 $km^2$ in area, is located in the southern and southeastern part of Kedah State. The basin is bordered in the north and the east by ridges of the Main Range of which height ranges from El. 500 to more than 1,000 m. The southern watershed is a warped ridge, descending from El. 1,000 m in its eastern end to the coastal alluvial plain. In the west, a ridge with 200 m to 600 m of ground height divides the Muda basin from the Kedah river basin, and its southwestern extension is a chain of low hills which divides the small Merbok river basin and the Muda river basin.

The Muda river basin is largely occupied by intrusive granites of Mesozoic era, which compose the mountainous area in the eastern part of the basin and stretch west to the middle reach of the Muda river and up to Mt. Perak (El. 865 m).

Sedimentary facies ranges in their age from Ordovician to Triassic.

Silurian Mahang Formation and possibly Ordovician to Permian Sungai Petani Formation, which are developed in the area from Kuala Ketil to the north of Jenian, are mainly composed of argillaceous rocks accompanied by cherts and local interbeds of sandstones. Baling Formation, developed in the middle reaches of the Ketil river near the contact with granite, is strongly folded complex of shales and slates, arenaceous rocks largely altered into quartzites and hornfels, and limestones often crystalline. The Baling Formation develops across the watershed to the valley of the Rui river in the upper Perak river basin (including the contemplated Rui dam site). The vicinity of Baling and the Rui river is the contact zone of intrusive granite and the Silurian Baling Formation, with intensive hydrothermal influences at places. Cassiterite ore deposit is being mined in this area.

In the upper reaches of the Muda river develops Triassic Semangol Formation which overlies unconformably the above Paleaozoic sediments. It is composed of interbedded sandstones and shales. Also locally but frequently developed member of this Formation is gritty sandstones and conglomerates which consists of angular lithic particles and rather small rock fragments of quartzites, cherts and argillaceous rocks. (The contemplated Beris and Tawar Muda dam sites are situated in this province.) The Semanggol Formation is also exposed in the surroundings of the lower reaches of the Ketil river and south.

Strikes of bedding and axes of mild folding show the north-southerly trend in general, except for the areas near the intrusive granites where some irregularities of strikes and intensive foldings are observed. Long stretched faults show dominantly northwesterly trend. Subordinate younger faults with northeasterly trend intersect the former at places.

Quaternary plain with approximately 20 km of width is developed in the coastal zone near the river mouth, 20 km north of Butterworth.

(4) Kerian river basin

The Kerian river basin, 1,420 $km^2$ in area, covers the southernmost parts of Pulau Pinang and Kedah States. The Kerian river forms a part of the southern border line of Kedah State. Main source of the Kerian river is in the granite ridge on the eastern divide of the basin, studded with the peaks as high as 1,200 to 1,800 m in ground height. The granite ridge branches toward west to form the northern watershed of the basin. The southern watershed consists of low hills in the province of Triassic sedimentary rocks and Quaternary deposits.

Other than the Mesozoic intrusive granites which are wide-spread in the eastern and the northern parts of the basin, the geological units exposed in the basin are Silurian Mahang Formation, Triassic Semanggol Formation and Quaternary deposits; each latter superposed on the former unconformably. The Silurian Mahang Formation, exposed in a part of the northern watershed and the middle reaches of the Kerian river, is composed of flagstones, shales and cherts with occasional sandstone interbeds. General trend of the bedding planes is northeasterly strikes and often very steep dips. The Triassic Semanggol Formation consists of sandstones with shale and chert interbeds and is developed in the southern part of the basin. The boundary between the provinces of the Semanggol Formation and the Mahang Formation in the north is believed to be a series of northwesterly faults.

Nearly a third of the basin area is covered by unconsolidated Quaternary deposits.

(5) Other river basins

The Merbok river basin, 520 $km^2$, is largely covered by dominantly argillaceous Sungai Petani Formation of Palaeozoic. The rest is the coastal alluvium.

The basins of the Perai river, the Juru river and the Jawi river, 895 $km^2$ in total area, located in Butterworth - Parit Buntar - Kulim area, are for the most part situated in the zone of Quaternary deposits along the coast. The upper reaches of the Perai river and the Jawi river are in the granite hills.

## 3. GEOLOGICAL INVESTIGATION

The field geological investigations as described below were performed in the period from December 1982 to March 1983.

- Surface geological exploration of the area for six dam schemes, including contemplated dam sites, reservoir areas, quarry sites and other areas concerned.
- Surface geological mapping of dam sites and reservoir areas in scale of 1/63,360 (inch/mile).
- Surface geological mapping of dam sites in scale of 1/1,000.
- Core drilling with standard penetration test and field permeability test for 950 m of total length and 32 bore holes, of which breakdown is shown in Table 2. Drill core samples are preserved in a storehouse of MADA, Alor Setar.

Permeability tests in the bore holes were made in the method of Lugeon test by installing packer at the top of the test section and measuring the rate of injected water under constant pressure. In case when packer could not be installed effectively the test was made in the falling head method of gravity permeability test, where drop of a raised water table in casing pipe which has been inserted up to the top of the test section was recorded as against elapse of time. The test results were presented in Lugeon unit and/or coefficient of permeability. Equations used for the calculation were as follows:

- Lugeon unit

$$Lu = \frac{Q}{L.H} \times 6 \times 10^4 \quad \ldots\ldots (1)$$

- Coefficient of permeability in case of Lugeon test

$$k = \frac{Q}{2\pi L.H} \cdot Ln\frac{L}{r} \qquad \text{when } L \geqq 10r \quad \ldots\ldots (2)$$

$$k = \frac{Q}{2\pi L.H} \cdot \sinh^{-1}\frac{L}{2r} \qquad \text{when } 10r > L \geqq r \quad \ldots\ldots (3)$$

where, Lu: Lugeon unit

k : Coefficient of permeability (cm/s)

L : Length of test section (cm)

H : Water pressure presented in head (cm)

Q : Injection rate of water ($cm^3$/s)

r : Radius of test hole (cm)

- Coefficient of permeability in case of falling head method

a) For unsaturated zone

$$k = \frac{r'^2}{2L(t_2 - t_1)} \left( \frac{\sinh^{-1} \frac{L}{r}}{2} \cdot Ln \frac{2H_1 - L}{2H_2 - L} - Ln \frac{2H_1H_2 - LH_2}{2H_1H_2 - LH_1} \right) \ldots \quad (4)$$

b) For saturated zone

$$k = \frac{r^2}{2L(t_2 - t_1)} \cdot Ln \frac{L}{r} \cdot Ln \frac{h_1}{h_2} \qquad \frac{L}{r} > 8 \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

where, k : Coefficient of permeability (cm/s)

L : Length of test section (cm)

r : Radius of test hole (cm)

r' : Inside radius of casing pipe (cm)

$t_1$, $t_2$: Time when water levels are measured in hole (s)

$H_1$, $H_2$: Length of water column from bottom of test interval to water surface in casing pipe, measured at time $t_1$ and $t_2$ (cm)

$h_1$, $h_2$: Depth of water level from top of casing pipe, measured at time $t_1$ and $t_2$ (cm)

In the attached plates, permeability is presented in terms of Lugeon unit. Conversion is made with the equations (1) and (2), or the following:

$$Lu = \frac{1.6 \times 10^5}{Ln \cdot L/r} \cdot k \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

No test has been done under the condition for the equation (3), that is, with length of test section less than ten times the radius of test hole; hence the equation (3) is actually not used.

# 4. GEOLOGICAL AND GEOTECHNICAL EVALUATION OF THE CONTEMPLATED DAM SCHEMES

## 4.1 Badak-Temin Dam

Badak Temin dam site is located on the Temin river in the upper Kedah river basin and at 5 km east-northeast from Changlun, a town on the Jitra-Sadao highway. The site is easy to approach with vehicles through an all-weather motor road from Changlun to Sintok. The contemplated dam axis is located within 400 m north from the bridge on the Temin river. The reservoir area is also fairly accessible by four-wheel drive cars through the road network in the rubber plantation which occupies large area upstream of the dam site.

The Temin river rises on the hill about 5 km north of the dam site and flows down almost straightly southward to the dam site. The Badak river joins the Temin river from the left side at about 500 m upstream of the dam site.

The area is characterized by wide open valley and outstandingly flat topography in the late stage of extensive side erosion. Remnant low hills are scattered in places.

On the dam axis the river shows large meander in the 650 m wide alluvial flat, with 26 m of ground height at the riverbed. The dam abutments on both sides of the river are on ridges lower than El. 80 m. At El. 50 m, the distance between the ridges is approximately 1,025 m.

The dam site and the reservoir area is situated in the geological province of areno-argillaceous group of the upper Devonian to Triassic Kubang Pasu and Singa Formation. The bedrock consists of sandstones, shales and siltstones.

The sandstones are grey, fine to medium grained and hard in fresh condition. There are some silicified layers on the right bank ridge. They are discoloured to light grey, white and occasionally purple when weathered. Also, weathered sandstones exposed on the outcrops are generally more friable than in fresh ones.

The shales are dark grey coloured, hard to moderately hard. In weathering, they are softened and discoloured to yellowish brown and reddish brown. The siltstones, grey and moderately hard, are intercalated as rather minor member.

Lenticular quartzite layers are located at places in the reservoir area.

Bedding planes are monoclinic with eastward dips in varied degrees ranging from 20 to 55, tending to be steeper to east.

Sandstones are dominantly developed on the right bank, or the west bank, of the dam site and the reservoir. The right abutment of the dam site is largely composed of the sandstones with minor intercalations of shale layers. The shale increases its proportion toward the left bank, or to east. Bedrock under the riverbed and on the left bank is alternating sandstones, shales and siltstones. Further eastward, in the reservoir area around the Badak river which joins from the east, the bedrock is composed dominantly of shales.

River alluvial deposit, consisting mainly of medium sand, fills the bottom of the valley widely. Its thickness shows 6.1 m, according to the core drilling BT-2. In the other part of the flood plain in the bottom of the valley where the surface of the alluvial deposit is higher, it is presumably thicker by the figure of the increased height. Thereby it is assumed that the bottom of the river alluvial deposit lies at around El. 19 m.

The bedrock of sandstone and shale alternation under the alluvial deposit is fresh or only slightly weathered. In spite of cracky appearance of drill core samples up to 10 m of depth, water pressure test indicates it highly water-tight with less than 1 of Lugeon unit. The bedrock at El. 19 m, immediately under the river alluvial deposit, is deemed to provide sufficiently competent foundation for the impervious core zone of fill-type dam. Hence, depth of required excavation in the bottom of the valley will be 6 to 12 m, varying locally, for unconsolidated sandy deposits. For foundation of shell zones of the fill dam, the alluvial sand appears too loose, as is seen in the results of standard penetration tests in the bore hole BT-2 which indicate only 3 and 5 of N-value. This seems to require removal of almost all alluvial deposits for the foundation of the shell zones as well.

The above judgement is based on the result of only one core drilling in the riverbed section. Detailed investigations with more bore holes will be required in the future stages of study.

The slope on the right abutment of the dam site is covered by thin top soil and thicker residual soil, the product of decomposition of the bedrock. In the bore hole BT-1 the residual soil is formed up to 3 m of depth and the underlying sandstones are intensively weathered to the depth of 6.5 m. Moderate weathering develops up to 11.5 m of depth. By 6.5 m deep excavation, the surface of the moderately weathered sandstones will provide competent foundation for impervious core zone of some 30 m high fill-type dam. Rather high permeability between 10 and 20 Lugeon unit in the weathered rock zone can be improved by grouting. On the other hand, the shell zone of the dam requires only 3 m of foundation excavation to reach to the top of the intensively weathered rock.

On the left bank, residual soil shows about 6 m of thickness. The underlying bedrock of sandstones and shales is weathered up to 9 m, that will be the depth of foundation excavation. However, shales are deeply fractured in the bore hole BT-3 and permeability shows generally high value up to 30 m deep bottom of hole, occasionally more than 20 Lugeon unit. Evidence of shear and slickensides in the shale core samples indicates existence of fault. Concrete replacement of fault below the foundation level and intensive grouting of the fault zone may be necessitated.

Serious geotechnical difficulties are not envisaged for the dam site so far. The fault will require no more than ordinary procedure of fault treatment. The main defect of this dam site is outstanding length of the dam axis that results in large dam volume.

The reservoir area is flat with very mild slopes. No substantial threat from sliding is found. There is no evidence of probability of noticeable leakage through bedrock in the reservoir rim.

Sandstone is the only conceivable rock material for the dam which is obtainable within a reasonable distance. The sandstone ridge on the right bank, however, is low and rather thin for rock quarry. Reliable quarry site is located at Bukit Telipong, a massive sandstone hill with 380 m of ground height, approximately 10 km west from the dam site. There are hard silicified sandstones which may be usable for concrete aggregate as well. For possibility of alternative quarries nearer to the dam site, close investigations by core drilling will be required in the future.

## 4.2 Durian Dam

Durian dam site is located on the Durian Burong river in the Kedah river basin, and at about 5 km north of Padang Sanai. The site is easily accessible by vehicles through the paved road up to Padang Sanai and then by way of unsealed all-weather road of sugarcane plantation. Roads for four-wheel drive cars are well developed up to the back water of the reservoir and beyond.

The reservoir splits into the basins of two rivers immediately upstream of the dam site; a branch stretches northward along the main stream of the Durian Burong while the other develops northwestward along the Selaya river, a right side tributary.

The reservoir area is situated in wide valleys among ragged hilly region with steep slopes. The topographic feature changes downstream from the dam site to mildly undulating peneplain. The section along the dam axis is very flat and wide.

The river flows south-southwestward with small meanders in the dam site. The riverbed is at El. 45 m on the dam axis. An alluvial flood terrace, 3 m high and 100 m wide, is developed on the left side of the river channel. On the right bank developed is approximately 350 m wide terrace of sugarcane field which is inclined very mildly toward the river channel. This terrace on the right bank is about 8 m higher than the riverbed at its lower end and composed of bedrock and overlying residuum. What can be called terrace deposit of fluviatile origin is rarely observed. The flat area between the rises of both abutments is about 500 m wide.

The dam and reservoir area is situated on the terrain of sandstones, shales and siltstones, of which age is believed to be Triassic to Jurassic. Intrusive granite is located in the upper reaches of the Selaya river. No remarkable alterations are observed in the vicinity of the granite zone, but strikes of the bedding planes appear to be considerably disturbed.

The sandstone is grey to dark grey coloured, fine to medium grained and occasionally silty, and hard to moderately hard in fresh condition. It is softened and discoloured to yellow brown, orange or white when weathered.

The shale and the siltstone are grey or dark grey coloured, homogeneous and hard to moderately hard. They are changed into variegated clayey soft rocks by weathering.

Bedding planes in the dam site strike generally at N50°W and dip around 45° southwestward. From dips in opposite ways which are prevalent in the area to the west, a synclinal axis is assumed in the west of the dam site. This local folding is deemed due to the granite intrusion in the north.

Bedrock of the dam site is alternating sandstones and shales, dipping downstream. Upper part of the bedrock is altered into residual soil by intensive weathering. In the bore hole DR-1 on the right abutment the clayey residual soil with surfacial top soil has 2 m of thickness, below which it makes gradual transition to intensively weathered shale. Moderately weathered shale which can be foundation for the impervious core zone of fill-type dam is encountered at 8.5 m of depth. It seems that the thickness of residual soil and accordingly the depth of surface of weathered rock vary locally. A test pit in the downstream sugarcane field shows more than 3 m thick residuum. On the left abutment where the slope rises with about 1/3 of gradient, residual soil is 4 m thick and the underlying weathered shale is sufficiently stable for dam foundation.

The residual soil appears to be competent for foundation of shell zone of fill dam. In the standard penetration test it shows more than 15 in N-value. Some 2 m of scraping of the layer including organic matter will be sufficient for the foundation.

In the centre of the dam axis, the bore hole DR-2 drilled at the end of the right bank terrace revealed 7 m thick residual soil and underlying 4 m thick intensively weathered zone, below which fresh sandstone was encountered. In the riverbed, it is deemed that the fresh rock zone lies within 5 m in depth.

Some fractures are observed in shales in each bore holes. Permeability shows often higher values than 30 in Lugeon unit on the both abutments. Intensive grouting operation will be required to improve it into substantial water-tightness below 4 Lugeon unit. Permeability in the bedrock under the riverbed is fairly low.

Fresh rock is encountered at the depth of 10 to 20 m.

It is probable that there are some faults of rather minor scale, as suggested by some fractures in the drill core samples, which, however, would not cause serious difficulties in treatment.

Conceivable quarry site is a massive hill with 380 m of height, located 3 km north from the dam site. It produces hard silicified sandstones. Proportion of unusable shale interbeds should be checked by core drilling in the future stage of investigation. Granite in the upstream area seems to be inferior as quarry site because of longer distance and thick weathering.

No evidence of land sliding is found in the reservoir. Though some minor slip-downs of residual soil on slopes are possible on impounding the reservoir, they will not be of such a scale as to threaten the safety of the reservoir and the dam. No possibility of substantial leakage through the reservoir is envisaged.

### 4.3 Sari Dam

Sari dam site is located on the Sari river in the Kedah river basin and at 7.5 km west-northwest of Padang Sanai. The site is accessible by four-wheel drive cars through a road of sugarcane plantation which leads from a Kuala Nerang - Padang Sanai paved road up to the reservoir area of the Sari dam.

The dam and reservoir will be situated in the area of ragged hills with ridges of El. 200 to 400 m. The valley has 100 m to a few hundred meters of width in the flat or mildly inclined bottom, except for some parts of construction. The dam site is located at one of the constructions in the most downstream ridge of the hilly region. The Sari river, about 10 m wide in the river channel, flows eastward at El. 52 m in the dam site. The slope on both banks rises at around 1/1.5 of gradient almost immediately from the river brinks.

The dam and reservoir area is situated in the geological province of Triassic to Jurassic sandstones, shales and siltstones, which belong to the same formation as those in the Durian dam area. Lithological characteristics are common with those in the Durian dam, 8 km to the east. Intrusive granites are exposed at about 7 km west and nearly the same distance to northeast from the dam site. Presumably due to the granite intrusion, some alterations into hornfels and quartzite are seen in the northern rim of the reservoir area. Schistose argillaceous rocks are also found in this zone.

Bedding planes show consistently north-south trending strikes and eastward dips from 45 degrees up to vertical. While general feature of the bedrock is sandstone and shale alternation, a highly shale-dominant zone is located in the middle part of the reservoir and a zone of hard sandstone is located in the dam site, both extending from north to south.

In the dam site, the zone consisting largely of hard medium sandstone develops across the river covering the ridges on both banks where the dam axis is laid out. Including occasional intercalations of shale layers, its width covers about 280 m along the river. With averagely 55 degrees of dip in view, thickness of the zone is estimated at 220 m. Both upstream and downstream from this zone developed are the sandstone and shale alternations.

The sandstone in the dam site as well as the intercalated shale is hard and stable in fresh condition. Covering of residual soil appears to be within 2 m, if any, in the zone of hard sandstone. On the dam axis up to El. 100 m, soil is very thin and weathering is up to only 5 m of depth. Fresh rock foundation is exposed by 3 m of excavation on the right bank and in the riverbed, and by 5 m of excavation on the left bank, for impervious core zone of fill dam. Further, the around 10 m deep foundation excavation on both abutments and the 3 m excavation in the riverbed would enable construction of concrete gravity dam.

Excavation for shell zone of fill dam will be required only to remove the surfacial layer containing organic material.

Permeability shows often 20 to 30 Lugeon unit on the right bank, while it is less than 20 and even less than 5 at 30 m of depth on the left bank and under the riverbed. The parts of high permeability are to be improved by grouting.

Rock material for fill dam and concrete aggregrate is obtained within a short distance by opening quarry in the ridge on either bank in extension of the said hard sandstone bed. The quarry will supply sufficient quantity of rock material, whereas the favourable narrow valley at the dam site will require rather small dam volume.

From geotechnical viewpoint, the Sari dam site has many favourable features; in its topographic narrowness, its hard and stable foundation bedrock and the location of quarry in a short distance.

Neither possibility of hazardous landsliding nor substantial leakage through bedrock is envisaged for the reservoir area.

There is a saddle on the divide of the reservoir rim, located about 1 km southwest of the dam site. According to the topographic map in scale of 1/10,000, the saddle is at approximately El. 85 m. Provided that the maximum high water level be at El. 85 m, height of the saddle dam would be about 6 m from the ground surface. The saddle forms a rather wide open topography with nearly 100 m long flat section and mild slopes on both sides. Bedrocks of the saddle dam site are alternating sandstone and shale. Residual soil and intensive weathering appear to develop to the depth between 5 and 10 m.

4.4 Tawar-Muda Dam

Tawar Muda dam site is located on the main stream of the Muda river and at 2 km east-northeast of Nami. The site is accessible by four-wheel drive cars through the road of rubber plantation from Nami.

The surroundings are rugged hilly area with peaks of 200 to 400 m in ground height. The valley has wide flat section in the bottom and mild slopes on the sides in the vicinity of the dam site. Such wide valley extends to about 5 km upstream from the dam site.

The Muda river, flowing southwest, meanders strongly in the wide bottom of the valley. In the originally contemplated dam site, distance between the slopes on both banks is 530 m at El. 80 m. The riverbed is at El. 52 m on the dam axis. A 200 m wide terrace is formed at around El. 67 m on the left bank. The left abutment rises with about 1/4 of gradient up to a peak at El. 180 m. The right abutment, with 1/3 of gradient, is on an isolated ridge between the Muda river and the Tributary Tawar river. The contemplated plan comprises construction of a subordinate dam on the Tawar river and connection of two reservoirs.

The valley of the Tawar river is also wide open, with the bottom at El. 42 m and 750 m of width at El. 80 m. The Tawar river runs southward at the foot of the left bank slope. A flat terrain with approximately 65 m of ground height is extensively developed on the right side between the river and the right bank slope.

The bedrock in the dam and reservoir area is composed of sandstones, shales and occasional lenticular intercalations of gritty sandstones and conglomerates, which are the members of Triassic Semanggol Formation.

The sandstones are light grey, grey and bluish grey coloured, fine to medium grained hard rock in fresh condition. Some are highly siliceous. Weathered it is discoloured to yellowish brown, white, and sometimes purple.

The shales are grey to dark grey coloured and moderately hard in fresh condition. They bear latent cleavages in common in similar orientations as the bedding plane and are apt to break along those cleavages when shocked. However, as a mass, they are fairly strong and not very flaky. They are weakened and discoloured to yellowish brown, reddish brown and white by weathering.

The gritty sandstones and conglomerates are rather minor members in the Tawar Muda dam site, but well developed in the southern area around the Beris river. The gritty sandstone is largely composed of angular to sub-angular particles of rock fragments, grey coloured in general, medium grained and very hard. The conglomerate is made of angular, sub-angular and round fragments of chert, argillaceous rock and quartz, ordinarily of granule and pebble size, with the gritty sandstone as matrix. It is characteristically the aggregate of many angular to sub-angular rock fragments of small size and various colours. While conglomerate is the term of customary usage for this member, the term of polymictic lithrudite has been given appropriately by Teoh Lay Hock, Geological Survey of Malaysia (1974). Relation between the gritty sandstone and the conglomerate is very often gradual transition.

General trend of strikes of the bedding planes is north-northeasterly. Foldings are observed on the western ridge of the reservoir and the saddle dam site with the axes trending in the same direction. A fault is probable to run also north-northeasterly on the right bank of the Muda river in the vicinity of the dam site.

The hard sandstone is dominantly developed on the western ridge, which is the right abutment of the saddle dam. It also dominates in the ridge on the left bank of the main dam site. Between these two sandstone zones lie a dominantly shale zone covering most part of the Tawar river valley and a zone of sandstone and shale alternation covering the valley of Muda river main stream. These two zones are assumed to be separated by a fault. Following the general trend of geological structure, those zones stretch in the north-northeasterly direction. To the east from the above zones an extensive area of sandstone and shale alternation is developed.

In the main dam site, the left abutment composed mainly of sandstones is covered by residual soil with 6 m of thickness at the height of El. 110 m (bore hole TM-4) and the underlying weathered zone is only 1 m thick. The fresh rock below it seems rather cracky and inflicted with minor faults. Such defects are to be treated by grouting. It is probable that the residual soil be thinner in the lower parts of the abutment. On the right abutment which is composed of the sandstone and shale alternation, the bedrock is intensively weathered up to 12 m of depth. Residual soil and intensive weathering is also as deep as 7 to 13 m under the terrace in the valley bottom, whereas under the riverbed the moderately weathered rock which is competent for foundation of impervious core zone is reached by excavation of a few meter thick river alluvium. A minor fault fracture with 20 cm of width is located in the bore hole TM-2 near the riverbed.

The hill with about 125 m of ground height at the top, which is partly the right abutment of the main dam and partly the left abutment of the subordinate dam, consists of sandstone and shale. Weathering seems to be considerably thick in the higher part of the hill. The distance between the locations of those two dam abutments is approximately 1 km along the ridge of the hill, and 550 m as the crow flies.

The left abutment and the 550 m wide flat in the valley of the subordinate dam site are underlain by shale beds. Thickness of residual soil plus intensively weathered rock layer ranges from 4 to 8 m. In the riverbed of the Tawar river, overburden upon the competent foundation rock is deemed thinner.

The right bank abutment of the subordinate dam site is composed of sandstone, gritty sandstone and conglomerate. Residual soil is thin and the bedrock is intensively weathered to 5 m of depth.

Residual soil is generally dense and stiff enough for foundation of shell zones of some 30 m high fill dam.

Permeability in the bedrocks is generally lower than 10 Lugeon unit for both main dam and subordinate dam. In the zone deeper than 20 m, it shows less than 3 in every bore hole. No grouting will be required, nor will be effective, for the zone below 20 m of depth.

For the reservoir area, the slopes are stable and not likely to incur large-scale land slidings, except for local minor slip-downs. The bedrocks are so water-tight and the reservoir rim is so thick that any possibility of leakage through the bedrocks on the reservoir rim is not conceivable.

Rock material will be obtained from the sandstone bed in the ridge on the left bank of the main dam site. This ridge stretches south across the Sok river and the Nami - Gubir road. The sandstone can be obtained also in the ridge on the right bank of the subordinate dam site. The quantity is sufficient. These sandstones are hard enough for concrete aggregate as well.

It seems that no geotechnical difficulties are envisaged for this dam site. The required foundation excavation ranging from 4 to 13 m in depth is not intolerably deep. Quarry can be located almost adjacent to the dam site.

As for the main dam, an alternative axis has been contemplated at approximately 500 m upstream of the above dam site. Further, another axis or more can be contemplated within that 500 m of distance upstream. Those alternative axes have advantage of shorter length of dam crest than in the original axis, under the condition that the reservoir H.W.L. be at El. 75 m or lower. In the part of incised meander of the Muda river upstream of the original dam site, a low ridge higher than El. 80 m bulges from the convex side of meander toward the river channel, and thereby the width of the valley is only 160 to 350 m on those alternative axes.

No core drillings have been performed for those alternative main dam sites. Surface geological investigation indicates that geological condition in those site could be almost similar to that of the original site. The sandstone beds on the left abutment of the original site stretch north-northeast to the left abutments of the alternative sites, while the lower part of the valley and the right abutment are underlain by the sandstone - shale alternation in the alternative sites as well. On the left bank, there are no evidences to suggest deeper residual soil and weathering than in the downstream site. On the right bank where the said bulge of ridge is somewhat isolated from the slope behind it by a slight saddle of El. 75 to 80 m of height, weathering is probably deeper than in the original site. However, considering that the ground height in this portion is nearly same as that of dam crest and hydraulic gradient of seepage is very low, deep foundation excavation would not always be necessary.

Although the alternative dam axes require confirmation of their sub-surface conditions by core drilling and geophysical exploration in the future, they seems fairly preferable to the original axis for remarkable decrease of the enbankment volume, if the reservoir H.W.L. does not exceed El. 75 m.

## 4.5 Beris Dam

Beris dam site is located on the Beris river, a tributary to the Muda river from the left side. The area of the scheme is approximately 10 km south of Nami. Two alternative dam sites are contemplated.

The alternative dam site No. 1 is located at 2.8 km east-southeast from Kuala Beris, the confluence of the Beris to the Muda river. The other alternative site No. 2 is at 2.3 km east-southeast of Kuala Beris as the crow flies, and about 750 m downstream along the river from the site No. 1.

The Beris river is accessible at approximately 1 km downstream of the dam site No. 1 by cars through an unsealed all-weather road leading from the vicinity of the left bank abutment of the bridge on the Muda river at Nami. A path on the right bank of the Beris leads to the dam site. The reservoir area between the dam site and the Gubir - Sik road can be accessible only through small paths which are partly obscured.

The dam and reservoir area is situated in the hilly region with peaks of various heights ranging from El. 200 to 450 m. In the upstream area of the reservoir around the Gubir - Sik road, mildly undulating terrain of low relief is developed.

The area is situated in the geological province of Triassic Semanggol Formation, consisting of sandstones, shales, gritty sandstones and conglomerates. Lithological characteristics are as described for Tawar Muda dam. Intrusive granite is encountered in the upstream end of the reservoir in the east of the Gubir - Sik road.

Sandstone and shale alternation covers widely the reservoir area. The lenses of the gritty sandstone and conglomerate are exposed in the vicinity of the dam site No. 2 and on the right bank of the Charok Sungkai river, right side tributary. Mt. Dada Ayam (El. 447 m) on the right bank side is composed of the same member.

Geological structure of the reservoir area shows roughly north to south trend as presented in general strike of the bedding planes, though considerable deviations are observed. Dip of the strata varies in gradient and direction. It is believed that the boundary between the upstream granite zone and the Semanggol Formation is faults of northeasterly and east-west trends. Also, a probable fault runs northwesterly through the dam site No. 1 and a saddle 500 m north of the dam site No. 2.

Though the slopes in the reservoir area appears to be covered by thick residual soil, those slopes are generally of mild inclination. It seems not probable that any rapid land slidings of large scale may jeopardize the safety of dam and reservoir. No evidences are observed for possibility of leakages through bedrock in the reservoir rim, which is sufficiently thick.

(1) Dam site No. 1

The Beris river, generally flowing west-northwest, shows incised meander in the hilly terrain. In the site No. 1 it runs northwestward at El. 56 m in the riverbed. It turns to southwest at about 100 m downstream. The left abutment is on a thin ridge descending from south, whereas the right abutment is on a massive slope. The slopes on the both banks show 1/2.5 to 1/3 of gradient. The valley section is 270 m wide at El. 85 m.

The bedrock is composed of sandstone and shale. Thin gritty sandstone and conglomerate layers are intercalated at places. The right abutment is mainly composed of hard sandstones with intercalations of grits. Residual soil covering the slope has 3.5 m of thickness. Intensive weathering reaches to 4.5 m of depth. In the riverbed and on the left bank, overburden shows only 2 to 3 m of thickness, whereas the shales and some sandstones in bedrock are intensively cracked and fractured. In core drilling of bore holes BR-5 and BR-6 in the riverbed and the left bank, cylindric core samples were rarely recovered and the rocks were crushed into drill slime in many parts. An evidence of fault clay was also found in BR-6.

In the right bank bore hole, permeability is lower than 3 Lugeon unit below the depth of 5 m.

The bore hole Lugeon tests in the riverbed and the left bank also indicate low permeability in the zone deeper than 15 m. If this was not incurred by possible decrease of the lengths of test sections due to collapse of the hole side, treatment of foundation in the aspect of leakage would not be difficult.

The above foundation condition would not reject the technical feasibility for construction of some 30 m high fill-type dam. It seems, however, that there is no reason to stick to this site if the alternative proves to be geotechnically better than it.

(2) Dam site No. 2

In the dam site No. 2, the Beris river flows west-southwest through about 10 m wide river channel at El. 52 m. The slopes on both banks rise almost immediately from the river brink. The slopes are as steep as 1/1.4 up to El. 80 to 90 m and show milder gradients of 1/2 to 1/3 in the higher parts. Width of the valley is 120 m at El. 85 m.

The dam site is situated in the middle part of a 600 m wide grit and conglomerate zone which extends in the north to south direction. The bedrock is exposed almost continuously along the river banks. The gritty sandstones and conglomerates are very hard and solid.

Bedding planes strike northeasterly and dip at 30° to 50° northwestward. Well developed joints are those with:

(a) northeasterly strike with southeast dip steeper than 35°,

(b) east-west strike with southward dip at around 60°, and

(c) northeasterly strike with vertical dip.

The river alluvial deposit is thin on the dam axis. Fresh or only slightly weathered rock foundation will be exposed by excavation within 2 m of depth. On the right abutment, slightly weathered gritty sandstone lies below residual soil with 2 m of thickness. On the left abutment where weathering, though not of serious grade, develops 14 m deep, the foundation excavation will be required up to 4.6 m of depth for impervious core zone of fill-type dam, to remove residual soil and cracky rocks. Foundation of shell zone requires only scraping the surfacial organic layer.

Hard foundation for concrete gravity dam will also be provided by 4 to 6 m deep excavation.

Permeability is generally lower than 20 Lugeon unit except at some particular open cracks in the surfacial zone. In the bore hole BR-2 in the riverbed, permeability shows less than 5 Lugeon unit in the zone deeper than 20 m. It is less than 3 below 5 m of depth on both abutments. Treatment of some parts with relatively higher permeability will be easily made by ordinary procedure of grouting, while a large part of foundation is practically water-tight in nature.

Rock material and concrete aggregates, if necessary, can be quarried from the ridge on the left bank which is composed of hard gritty sandstones and conglomerates.

The dam site No. 2 requires a subordinate dam at the saddle about 500 m north of the dam site. The necessary height of the saddle dam is about 15 m from the ground surface at El. 73 m. The saddle has rather flat section with slopes of about 1/5 gradient on both sides. The bedrocks are hard sandstones and shales. Residual soil is 3.8 m thick, according to the bore hole BRS-1 at the centre of the saddle, and intensive weathering develops to 4.5 m of depth. Below 4.5 m of depth lies the sandstone bed which is weathered but hard and stable enough for foundation of dam. Fractures in shales below 12 m of depth suggest that the fault zone through the dam site No. 1 stretches to this saddle. The narrower section and the smaller height of dam, as compared with the dam site No. 1, will render the treatment of the fault far easier at this site.

It seems evident that the scheme of the dam site No. 2 is more preferable than No. 1.

## 4.6 Rui Dam

Three alternative dam sites for the Rui dam scheme are on the Rui river, an upstream tributary of the Perak river. The area of the scheme covers the Rui river basin in the south of Kelian Intan on the Keroh - Gerik road for the dam and reservoir. The vicinity of Charok Pendiat, 14 km south of Baling, is contemplated for the powerhouse and penstock. The mountainous zone between the Rui river and Charok Pendiat is to be passed through by 6 km long tunnel.

The dam site No. 1, the most upstream alternative, is located about 3.5 km northeast of an existing power station at Pong village on the Rui river. The dam site No. 2 is located at 4 km southwest from Pahit village on the Rui river near the bridge of the Keroh - Gerik road, and at about 4 km downstream along the river from the dam site No. 1. The dam site No. 3 is another 2 km downstream from the No. 2 site along the meandering river channel and 1 km as the crow flies.

The area of the scheme is situated in a part of Main Range, which is topographically characterized by deep gorges and relatively high ridges. While the Rui river is in the proximity of El. 180 m in the dam sites, the ridge between the reservoir and the powerhouse site reaches to El. 745 m at the peak. The Rui river flows north-northeastward with intensive incised meanders.

The area is situated in the geologic province of Silurian Baling Formation. Agrillaceous facies mainly comprising variegated shales, which is often phyllitic, is wide-spread in the dam and reservoir area. Bedding planes, striking north-northeasterly, are monoclinic with eastward dips from 30° to vertical. Lenticular beds of limestones are intercalated occasionally. The limestone is often crystalline, and its thickness varies from a few meters to several hundred meters. The limestone lenses are elongated in the north-northeastly direction, but they are not continuous for more than 2 km in length.

A continuous limestone zone is found running northeast through the middle part of the slope of western watershed. It has approximately 1.5 to 2 km of width. The limestones are often impure with argillaceous material. To northwest from this limestone zone develops a belt of contact zone with granite, consisting mainly of quartzite and hornfels, of which the former is altered from arenaceous rocks and the latter from argillaceous rocks.

Intrusive granite covers extensive area from the upper Rui basin and Charok Pendiat (the powerhouse site) up to Kupang on the Baling - Gurun road. Its branch stretches northeastward along the ridge of the left side divide of the Rui basin. The powerhouse and penstock will be located in the granite terrain.

The tunnel route will be laid out through the shales and the granite. Local lenses of limestone may be encountered.

General trend of bedding is northeasterly or north-northeasterly. Numerous northwesterly faults intersect it. In the other hand the area is frequently inflicted by hydrothermal alteration from granite intrusion. Intensive shearings and deterioration are observed in bedrocks at places. An example of such deterioration is seen on outcrops near Kelian Intan, where cassiterite ore deposit is mined. It is believed that there is potential reserve of cassiterite in the Rui valley.

For the reservoir area, there are no evidences for possibility of any hazardous land sliding of large scale on impounding. As for possibility of leakage, the faults are not likely to cause any substantial loss of water from the reservoir because of thick reservoir rim, except for the part close to the dam site. The limestone in the reservoir area has solution cavities and crevices occasionally, although it is generally massive. The observed largest crevice is 20 to 80 cm wide and about 10 m high; which is located on the left bank upstream of the dam site No. 1. Minor stalactites are observed in other opening. In general most of the limestones in the reservoir area is pinched out within 2 km or less distance surrounded by the shales, or cut off by faults. This condition seems to minimize the possibility of leakage through limestone cavities. The continuous limestone bed on the higher part of the left bank slope will be contact with the reservoir only in a small area at back-water. The limestone is impure, and no openings were found so far, though this does not deny existence of cavities absolutely. Intensive investigation will be necessary for the limestones in the future stages of the study.

(1) Dam site No. 1

The riverbed is at El. 184 m. The slopes on both banks are as steep as 1/1.4 in gradient. The flat at the bottom of valley shows about 40 m of width.

Bedrock is composed totally of dark grey shale. In spite of favourable topographic feature, the bedrock appears extensively sheared and deteriorated by the influences of faults and hydrothermal alteration. Two long faults are probable to run within 600 m to north and to south. It seems that the intermediate area between them, where the dam site is situated, is intensively inflicted with subordinate faults and shears, as revealed by core drilling.

Three bore holes at this site, one in the riverbed and the others on both abutments, show almost entire fracturing of the shale beds. The recovered samples are fragments and drill slimes. Packer for Lugeon test could not be set effectively and the falling head method was applied for measurement of permeability. The result shows fairly low values, except for the section up to 15 m of depth in the bore hole at the riverbed where coefficient of permeability shows around $1 \times 10^{-3}$ cm/s. It is probable that the obtained values of permeability may be lower than the actual due to collapse of the hole sides.

The above geological situation renders this site most unattractive, if not unfeasible.

(2) Dam site No. 2

The Rui river turns its direction from eastward to northward at 300 m upstream of the dam axis. In the dam site the river channel, 20 m wide, runs northward at El. 178 m, sub-parallel to the strike of bedding plane. The right bank slope rises immediately from the river brink, while the left slope is located behind the 100 m wide alluvial flat on the left bank of the river channel. Gradient of slope is 1/2 on the left bank and 1/1.2 to 1/1.5 on the right bank. The left abutment is on rather thin ridge projecting from west.

The bedrock is composed of shales with various colours; purple, bluish grey and yellowish brown. Bedding planes strike at N10°E in majority and dip eastward at around 60°. A white crystalline limestone layer and a grey limestone layer 2 m and 3 m thick respectively, are located in the bore hole RII-2 at the riverbed. Another intercalation of limestone layer is probable to exist on the right bank slope as indicated by limestone boulders at its foot. No outcrops of these limestones are found in the dam site.

The foundation condition under the riverbed is fairly good. Below 4 m thick river alluvial deposit, intensive weathering and loosening of phyllitic shale are terminated at 7 m of depth. The underlying crystalline limestone up to 11.6 m of depth is hard and solid, and free from any solution cavities so far as the drilling core samples are concerned. The subsequent dark grey shales and grey limestone are also fresh, hard and solid. Required depth of excavation for foundation of impervious core zone of fill dam is 7 m. Removal of organic soil with 2 to 3 m of thickness will be necessary for foundation of shell zone on the left bank flat. Lugeon test indicates virtually watertight condition of the bedrock below 10 m of depth.

In contrast with good geological condition in the riverbed section, the sub-surface conditions are poor in the abutments. In the bore hole RII-1 on the right abutment, residual soil is 5.5 m thick and an intensively weathered zone appears to terminate at 10 m of depth. However, in the deeper zone, repeatedly appears clayey deteriorations, fragmental core samples and sections of low core recovery. Packer could not be installed effectively in many cases, in which the falling head method was applied for permeability tests. Permeability shows not very high values, that is, around $1 \times 10^{-4}$ cm/s in coefficient.

On the left abutment, residual soil is as thick as 16.7 m, below which shales are intensively weathered or decomposed up to 24 m of depth. Weathered rock zone which is competent for foundation of impervious core zone is encountered at 24 m of depth. Permeability is similar to that on the right abutment.

The site will require intensive investigations in the future stage, including core drilling, geophysical exploration and adit excavation. Elaborate care will be necessitated for foundation grouting and contact of impervious core with the foundation rock in the stage of construction. Eventually this site is preferable to the dam site No. 1 on the basis of comparison, in spite of its yet very poor condition of foundation bedrock.

(3) Dam site No. 3

In the dam site No. 3 the Rui river flows east-northeast through the 20 to 30 m wide channel at El. 175 m. The river flow turns from southward to east-northeastward at 60 m upstream of the dam axis and from east-northeast to northward at 300 m downstream. The ridge of the left abutment is situated on the convex side of the incised meander.

The slope on the right abutment rises directly from the river bank at 1/0.8 of gradient, that turns gradually milder up-slope to the proximity of 1/2. On the left bank, a narrow flood terrace with 20 m of width is formed and the slope behind it shows about 1/2 of gradient.

While a limestone bed, less than 40 m in width, is located about 100 m upstream of the dam axis, the bedrock around the dam axis is totally composed of shales. The river alluvial deposit is estimatedly 6 m thick, underlain by competent moderately weathered rocks for foundation of impervious core zone of fill-type dam.

In the bore hole RIII-1 on the right abutment, intensively weathered zone develops under a 4 m thick residual soil up to 11 m of depth. Weathering is rather slight below 11 m, except for some sections with fragmental core samples.

On the left bank, it is revealed by the bore hole RIII-3 that reddish brown clayey residuum is 16 m in thickness, and intensive weathering is up to 21 m of depth. The underlying weathered shales are solid enough for dam foundation.

Only a few meters of excavation will be required for shell zone of fill dam.

Permeability shows around 30 Lugeon unit or less in the riverbed section. It is far lower on the left bank and approximately 10 Lugeon unit on the right abutment. Leakage can be treated by grouting. Intensive and concentrated grouting operation will be required for zones of high permeability. Permeability decreases to less than 10 Lugeon unit in the zone deeper than 20 m.

Existence of a fault is assumed in the northern part of the left bank, though not clearly observed on a large outcrop. This fault is deemed to run east-southeasterly across the left bank ridge in the higher part of the slope than the abutment. It is probably of minor scale, if any, and involves no serious difficulties.

The dam site No. 3 has relatively more reliable foundation condition than the other two alternatives, though the 21 m deep foundation excavation required on the left bank is a considerable defect.

(4) Quarry site

Limestone is the only massive hard rock material which is available within a reasonable distance. It can be obtained from small hills and ridges with large limestone outcrops which are scattered along the upstream Rui river. Quarry may have to be opened at more than one place. Distance as the crow flies is within 6 km from the dam site No. 3 and 5 km from No. 2. Hauling distance would be around 8 km through the bottom of the Rui valley.

Granite in the upstream area from Pong Power Station is far less economical for quarry site because of seemingly thick deterioration of the granites and the longer hauling distance.

Quartzites and hornfels are obtainable in the vicinity of the northwestern divide of the Rui basin, in which case, however, the hauling distance would be doubled as against the case of limestone quarry.

(5) Tunnel

A waterway tunnel, connecting the reservoir and the powerhouse, will be laid out through granite for about 5 km of length and through shales for one or two kilometers. It is probable that the tunnel intersects a few structural faults and many subordinate ones. There also is possibility of encountering the zones of hydrothermal alteration or deterioration in the shale bed. It appears that the granites are weathered deeply. It is recommended to make a geophysical profile of the tunnel alignment by means of seismic prospection.

(6) Powerhouse and penstock

The slope to the east of Charok Pendiat village on the Tiak river descends from the ridge at El. 880 m to about El. 100 m within 2.5 km of horizontal distance. In the lower part below El. 150 m, the slope shows mild gradient.

The bedrock is intrusive granite for penstock and powerhouse. Outcrops are rare and only granite boulders are observed scattered sparsely. It seems that intensive weathering is developed considerably deep.

## 5. FUTURE GEOLOGICAL EXPLORATION

More detailed geological explorations are required for the feasibility study and the detailed design of the schemes.

Core drilling, with standard penetration test and Lugeon test, has so far been performed in the rate of three bore holes for each dam site (including the alternatives), with each one hole on either abutment or in the river bank.

The further study of the schemes requires core drillings at more bore holes, which are allocated at 50 to 100 m intervals on the dam axis and in the up and downstream of the axis.

Geological condition of quarry sites should be confirmed by core drillings.

Seismic prospecting is to be made along the dam axis and several subordinate prospecting lines for the purpose of picking up every low velocity zones which are possibly fault zones.

The above mentioned items are common for all of the six dam schemes.

Core drilling and seismic prospecting are required for the saddle dam sites for the Sari dam, the Tawar Muda dam, the Beris dam No. 2 and the Rui dam No. 2 and No. 3.

The Rui scheme will require also (1) the excavation of adits, 2 m by 2 m in section and 50 m in length, on both abutments of dam site for in-site observation of fractured rocks, (2) the core drillings for the penstock and powerhouse site and (3) the seismic prospecting along the tunnel alignment. The Rui scheme also requires further detailed study about the limestone in the reservoir area; its solution cavities and their distribution and development.

Thereby the least quantity of geological investigation works required for the stage of feasibility study will be the proximity of the list as shown in Table 4.

## 6. SEISMICITY

Peninsular Malaysia is situated on a stable cratonic block of Sunda Shelf and accordingly in the region of very low seismic activity. This region covers the entire Peninsular Malaysia and the western half of Borneo.

According to the past study of seismicity in Indonesia (Ref. 21), this region is reported as the zone where expected average frequency of occurrence of shallow earthquakes of Magnitude 7.0 or more per square degree (of longitude and latitude) per century is approximately zero. The boundary of this zone runs in the northwesterly direction in the vicinity of the Peninsula through a little to west side of the center of Melaka Strait. To west from this boundary lies Sumatra Island with active seismicity.

The contemplated dam sites are located more than 120 km inside from the above boundary of very low seismicity zone.

To evaluate influence of earthquake upon the dam site, the following calculation estimates the maximum acceleration effected on the dam sites for the case that an earthquake of Magnitude 7.0 occurred on the said boundary within a neglectively small depth. Equations are as follows:

$$Mk = 2(M - 4.85) \quad \cdots\cdots \quad (7)$$

$$Ij = Mk + 4.605 \log\frac{Do}{D} + 2k(D - Do)\log e \qquad d \geqq 100 \text{ km} \quad \cdots\cdots \quad (8)$$

$$a = 0.45 \times 10^{0.5\ Ij} \quad \cdots\cdots \quad (9)$$

(Kawasumi's formula)

where, M : Magnitude in Richter Scale

Nk: Magnitude in Kawasumi's Scale, that is, JMA Intensity at the distance of 100 m from the epicenter

Ij: Intensity in JMA (Japan Meteorological Agency) Scale

d : Distance from the epicenter to the site (km)

D : Distance from the focus to the site (km)

Do: Distance from the focus to the point of 100 km from the epicenter (km)

k : Damping rate of S-wave (= 0.0192/km)

a : Maximum acceleration at the site

e : Base of natural logarithm

When d = 120 km, D = 120 km, Do = 100 km and M = 7.0, the maximum acceleration at the site (a) is 60.7 gal, that is, 0.062 g. It will be sufficiently safe to take 0.10 g for design value.

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# *TABLES*

## Table 1 STRATIGRAPHIC SEQUENCE IN PERLIS-KEDAH-PULAU PINANG REGION

| Era | Period | Ketil river, Baling | Mt. Jerai, Merbok | Lower Muda, Kerian, Kulim | Sungai Tiang | Alor Setar & Pulau Paya | Jitra & Perlis |
|---|---|---|---|---|---|---|---|
| Cenozoic | Quaternary | Alluvium, terrace. | Alluvium, terrace. | Alluvium, terrace. | Alluvium, terrace. | Alluvium, terrace. | Alluvium, terrace. |
| | Tertiary | | | | | | Bukit Arang Coal Bed (Semi-consolidated gravels, sand and clay) |
| Mesozoic | Cretaceous | Damar granite<br>Inas granite | Granites and associated rocks | Minor granite intrusion | | | |
| | Jurassic | Kupang granite | Quartz porphyries | Major granite intrusion | Granite intrusions | | |
| | Triassic | Semanggol Formation (sandstones, siltstones and shales, interbedded with cherts) | | Semanggol formation (Predominantly sandstones with siltstones, shales and cherts) | Semanggol Formation (Interbedded sandstone, siltstone, mudstone and shale, with interbeds/lenses of conglomerates at the top.) | Chuping Formation (Limestone and areno-argillaceous detrital strata). | Chuping Formation (Limestone, quartzite, sub-greywacke) |
| Palaeozoic | Permian | | Sungai Petani Formation (Interbedded shales and mudstones with minor sandstone-quartzites and limestones.) | Tawar Formation (shales and cherts) | | | |
| | Carboniferous | | | Sungai Petani Formation (Red shale, variegated shale, chert and some sandstones) | Kpg. Sena Formation (Argillaceous rocks, Mainly shale, with interbeds/lenses of arenaceous rocks.) | Kubang Pasu & Singa Formation (Areno-argillaceous detrital strata) | Kubang Pasu & Singa Formation (Areno-argillaceous detrital strata) |
| | Devonian | | | | | | |
| | Silurian | Baling Formation (Calc-silicate rocks, hornfels, shales, limestones-marbles, arenaceous rocks-quartzites) | | Mahang Formation (Dark flagstones, shales and cherts, with local interbeds of sandstones) | Mahang Formation (Predominantly argillaceous rocks, shales & mudstones with minor pods and lenses of sandstones and siliceous rocks.) | | |
| | Ordovician | | | | | | Setul Formation (Dark grey limestones and calcareous phyllites) |
| | Cambrian | | Jerai Formation (Quartzites and schist) | | | Machinchang Formation (Conglomerates, grits, quartzites, shales, sub-greywackes) | |

Unconformity

(Ref. 4 through 16)

Table 2 LIST OF CORE DRILLINGS

| Location | Hole No. | Depth (m) | S.P.T. (nos.) | Permeability Test (nos.) | Perforated Pipe (m) |
|---|---|---|---|---|---|
| Badak Temin Dam Site | BT-1 | 30 | 3 | 5 | - |
| | BT-2 | 20 | 5 | 3 | - |
| | BT-3 | 30 | 5 | 4 | - |
| Durian Dam Site | DR-1 | 30 | 5 | 5 | - |
| | DR-2 | 30 | 5 | 5 | - |
| | DR-3 | 30 | 2 | 5 | - |
| Sari Dam Site | SR-1 | 30 | - | 6 | - |
| | SR-2 | 30 | - | 6 | - |
| | SR-3 | 30 | 1 | 6 | - |
| Tawar Muda Dam Site | TM-1 | 30 | 1 | 6 | - |
| | TM-2 | 30 | 1 | 6 | - |
| | TM-3 | 30 | 7 | 6 | - |
| | TM-4 | 30 | 5 | 6 | - |
| Tawar Muda Sub-ordinate Dam Site | TMS-1 | 30 | 1 | 6 | - |
| | TMS-2 | 30 | 5 | 5 | - |
| | TMS-3 | 30 | 4 | 6 | - |
| Beris Dam Site 2 | BR-1 | 30 | 1 | 6 | 30 |
| | BR-2 | 30 | 1 | 5 | - |
| | BR-3 | 30 | 2 | 6 | 30 |
| Beris Dam Site 1 | BR-4 | 30 | 2 | 6 | - |
| | BR-5 | 30 | 2 | 4 | - |
| | BR-6 | 30 | 2 | 4 | - |
| Beris Saddle Dam Site | BRS-1 | 20 | 3 | 3 | - |
| Rui Dam Site 1 | RI-1 | 40 | 1 | 8 | 22 |
| | RI-2 | 40 | 1 | 8 | - |
| | RI-3 | 40 | 1 | 8 | 33 |
| Rui Dam Site 2 | RII-1 | 30 | 5 | 6 | 30 |
| | RII-2 | 30 | 6 | 6 | - |
| | RII-3 | 30 | 15 | 6 | 17 |
| Rui Dam Site 3 | RIII-1 | 25 | 5 | 5 | - |
| | RIII-2 | 20 | 7 | 4 | - |
| | RIII-3 | 25 | 15 | 5 | - |
| Total | | 950 | 119 | 176 | 162 |

## Table 3 GEOLOGICAL FEATURES OF THE DAM SITE

| Dam | Alternative | Foundation rock | Thickness of soil L/B | Thickness of soil Centre | Thickness of soil R/B | Depth of fresh rock L/B | Depth of fresh rock Centre | Depth of fresh rock R/B | Foundth Excavation L/B | Foundth Excavation Centre | Foundth Excavation R/B | Quarry | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Badak-Temin | | Sandstone(thick) on right bank) & shale (thick) on left bank. Devonian-Triassic | 6m | 6m | 3m | 10m ± 6 - 12m | | 10m± | Fill dam 9m | 6 - 12m | 6.5m | Siliceous sandstone, 10 km west from the damsite. | Fractures of shale on the left bank, with high permeability around 20 Lu, can be treated by grouting.<br>Topographically flat. |
| Durian | | Sandstone and shale, moderately hard. Triassic/Jurassic | 4m | 7m | 2m | | 10 - 11m | | Fill dam 4.0m | 11.0m | 8.5m | Siliceous sandstone, 3 km north from the damsites. | Fractures in river bed to the left bank, with more than 30 Lu of permeability.<br>Topographically flat. |
| Sari | | Sandstone with shales. Hard Triassic/ Jurassic | Very thin less than 1 m. | | | 4.5m | 1m | 4.5m | Fill dam 5.0m<br>Concrete dam 12.5m | 3.0m<br>3.0m | 3.0m<br>10.0m | Hard sandstone, within 1 km on the right bank. | Favourable topographically and geotechnically. |
| Beris | 1 U/S | Sandstone and shale. Triassic | 2m | 3m | 3.5m | - | - | 5.0m | Fill dam 3.7m | 3.0m | 4.5m | Grit, breccia, sandstone, 800 m downstream | Fractured zone runs through this site along northwest direction. Obviously inferior to the alternative located in downstream. |
| | 2 D/S | Grit, breccia, sandstone, hard. Triassic | 2.8m | 1.1m | 2.1m | 4.6m | 1.1m | 2.7m | Fill dam 4.6m<br>Concrete dam 6.5m | 1.1m<br>3.8m | 2.1m<br>6.0m | Grit, breccia, sandstone, within 1 km on the left bank | Favourable topographically and geotechnically. Fractured zone through the saddle dam can be treated by grouting and concrete replacement. |
| Tawar-Muda | 1 U/S | Sandstone and shale Triassic | Appro 5m | | | Presumably similar to No. 2 | | | Presumably similar to No. 2 | | | Same location as below | |
| | 2 D/S | Shale with sandstone, moderately hard Triassic | 8.0m | 5.0m | 1.0m | 15.0m | 7.0m | 22.4m | Fill dam 13.0m | 5.0m | 12.0m | Hard sandstone within 2 km on the left bank | Some fractures on the left bank, but permeability within the range of $10^{-5}$ cm/sec. |
| Rui | 1 U/S | Slaty shale and limestone, hard. Silurian | 2m | 3m | 1m | More than 40m | | | Not recommended as an alternative because of deep fractures. | | | Limestone in the reservoir area | Limestone in the reservoir will require detailed study about leakage in the future stages of investigation. Deep and irregular weakening of rocks by hydrothermal alterations. |
| | 2 | Slaty shale and limestone, hard Silurian | 16m | 5m | 5m | Deeply weathered and softened 29m | 7m | 25m | 24m | Fill dam 7m | 10m | Limestone as above | |
| | 3 D/S | Slaty shale, hard Silurian | 15m | 5m | 5m | 30m | 7m | 12m | 20m | Fill dam 7m | 10m | Limestone as above | |

Table 4 FUTURE GEOLOGICAL EXPLORATION FOR FEASIBILITY STUDY

| Site | Core Drilling | | Seismic Exploration | Adit |
|---|---|---|---|---|
| Badak Temin | | | | |
| Dam Site | 30 m x 14 = | 450 m | 2,000 m | - |
| Quarry | 40 m x 5 = | 200 m | - | - |
| Sub-total | | 650 m | 2,000 m | - |
| Durian | | | | |
| Dam Site | 30 m x 12 = | 360 m | 2,000 m | - |
| Quarry | 40 m x 5 = | 200 m | - | - |
| Sub-total | | 560 m | 2,000 m | - |
| Sari | | | | |
| Dam Site | 30 m x 6 = | 180 m | 1,200 m | - |
| Quarry | 40 m x 4 = | 160 m | - | - |
| Saddle | 30 m x 6 = | 180 m | 1,000 m | - |
| Sub-total | | 520 m | 2,200 m | - |
| Tawar Muda | | | | |
| Dam Site | 30 m x 7 = | 210 m | 2,000 m | - |
| Quarry | 40 m x 5 = | 200 m | - | - |
| Saddle | 30 m x 8 = | 240 m | 2,000 m | - |
| Sub-total | | 650 m | 4,000 m | - |
| Beris No. 2 | | | | |
| Dam Site | 30 m x 6 = | 180 m | 1,200 m | - |
| Quarry | 40 m x 4 = | 160 m | - | - |
| Saddle | 30 m x 4 = | 120 m | 1,000 m | - |
| Sub-total | | 460 m | 2,200 m | - |
| Rui No. 2 or 3 | | | | |
| Dam Site | 30 m x 20 = | 600 m | 2,000 m | 50 m x 2 = 100 m |
| Quarry | 40 m x 6 = | 240 m | - | - |
| Saddle | 30 m x 3 = | 90 m | 1,000 m | - |
| Tunnel | - | | 8,000 m | - |
| Penstock and P/H | 30 m x 4 = | 120 m | - | - |
| Sub-total | | 1,050 m | 11,000 m | - |

# FIGURES

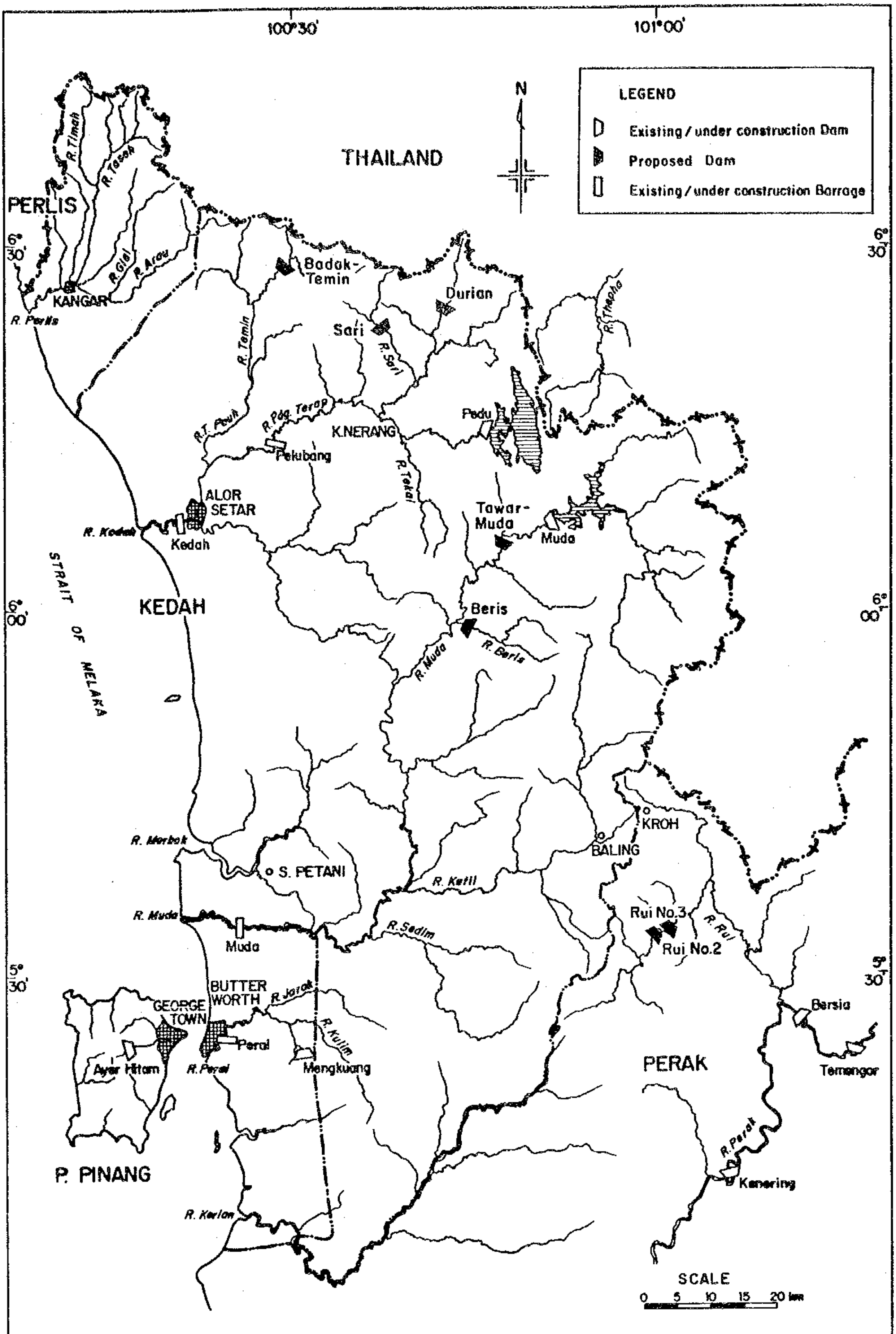


Fig. 1 Location Map

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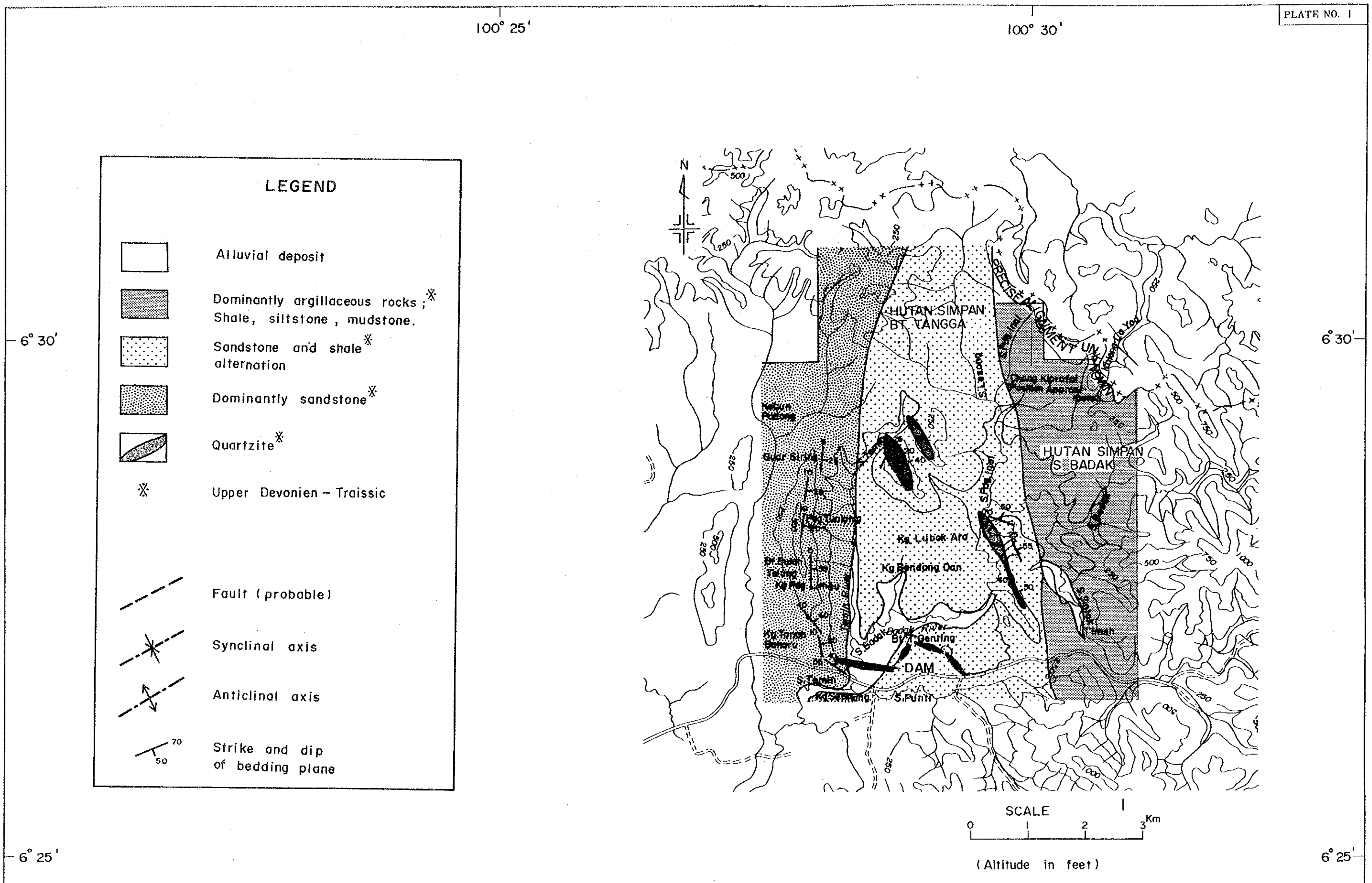
# PLATES

PLATE NO. 1




Geological Map of Dam and Reservoir Area, Badak-Temin

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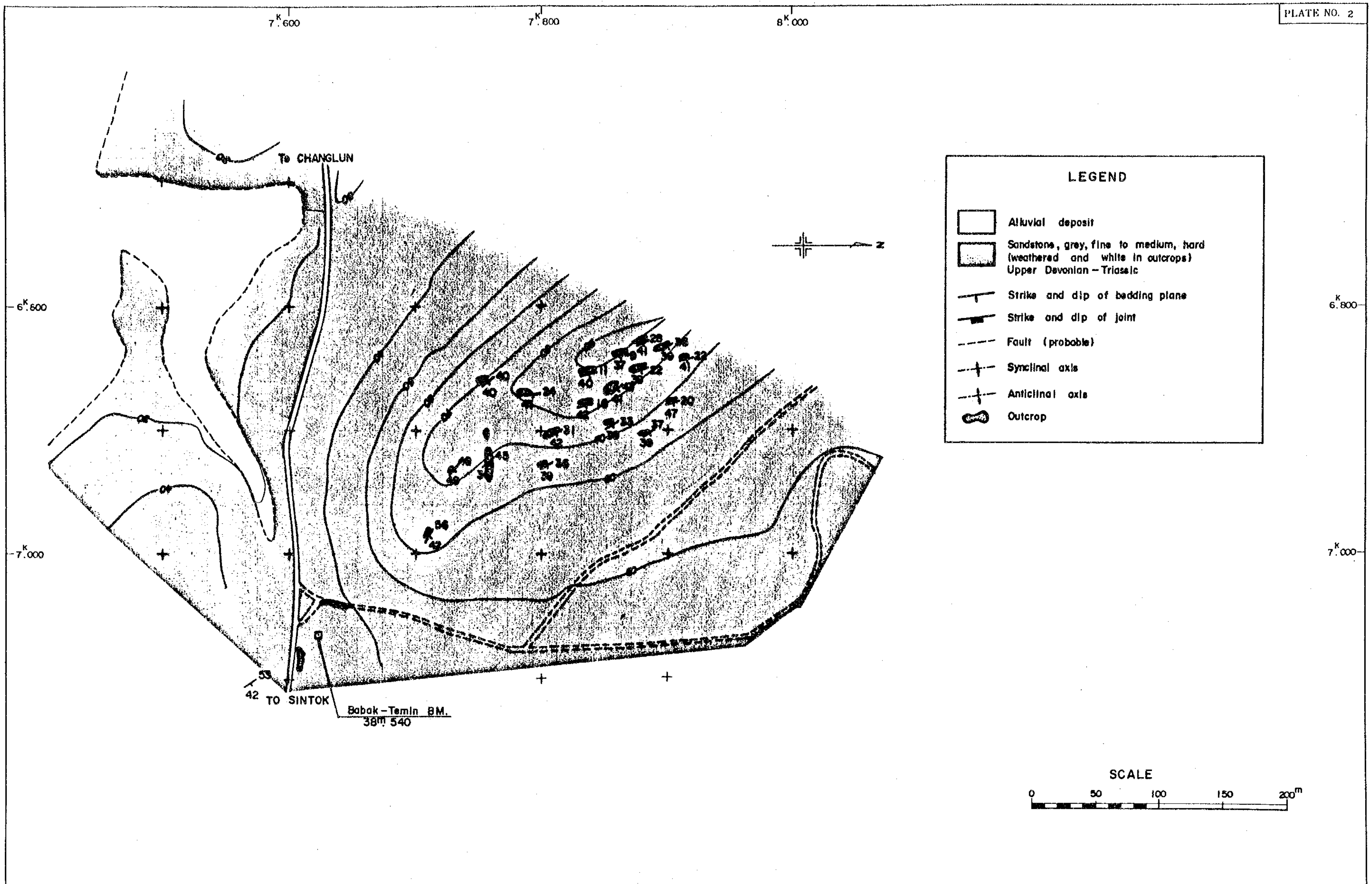
PLATE NO. 2




Geological Map of Spillway Area, Badak-Temin

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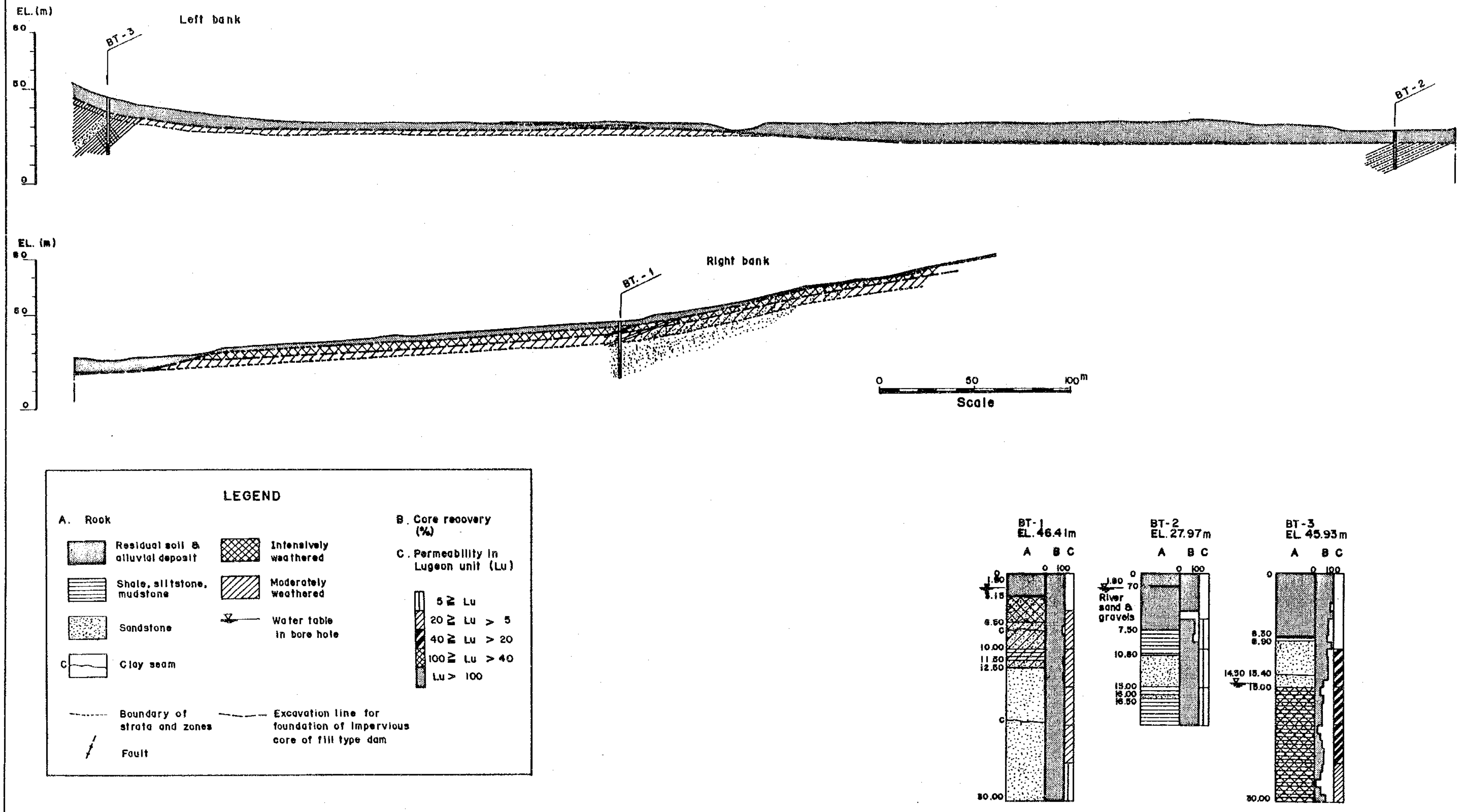


Geological Profile of Dam Site, Badak-Temin

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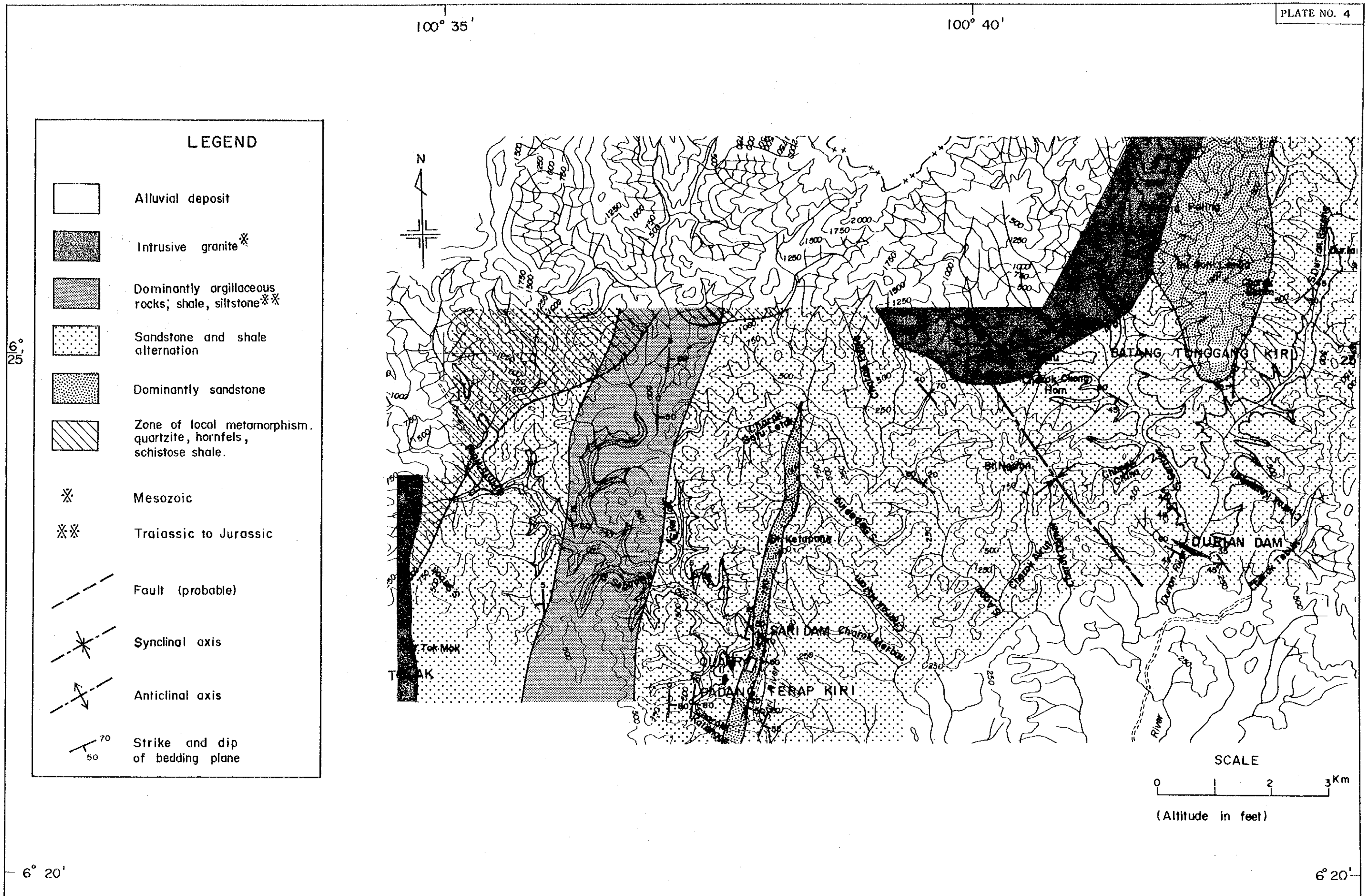
PLATE NO. 4




Geological Map of Dam and Reservoir Area, Durian and Sari

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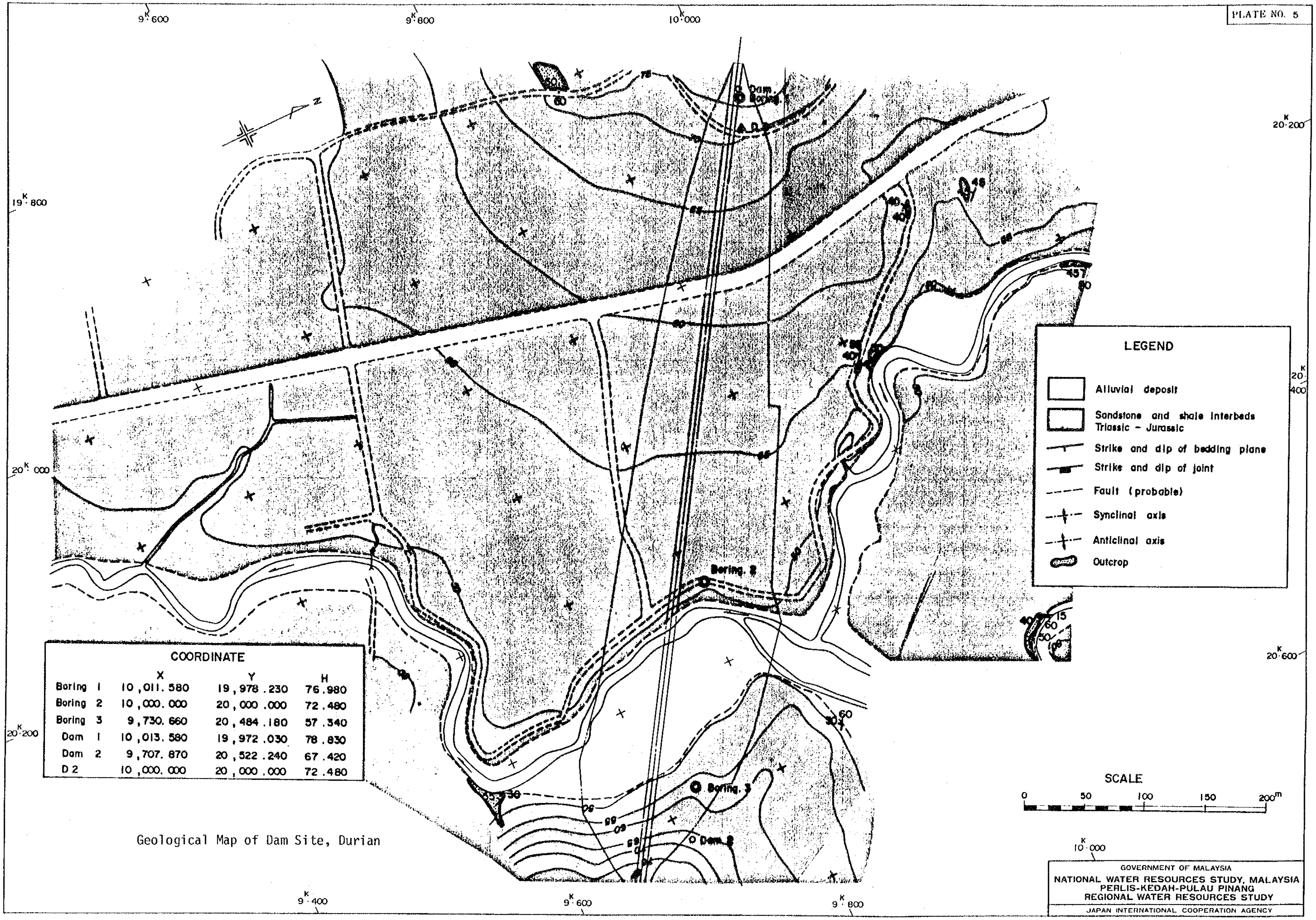
PLATE NO. 5




**COORDINATE**

| | X | Y | H |
|---|---|---|---|
| Boring 1 | 10,011.580 | 19,978.230 | 76.980 |
| Boring 2 | 10,000.000 | 20,000.000 | 72.480 |
| Boring 3 | 9,730.660 | 20,484.180 | 57.340 |
| Dam 1 | 10,013.580 | 19,972.030 | 78.830 |
| Dam 2 | 9,707.870 | 20,522.240 | 67.420 |
| D 2 | 10,000.000 | 20,000.000 | 72.480 |

Geological Map of Dam Site, Durian

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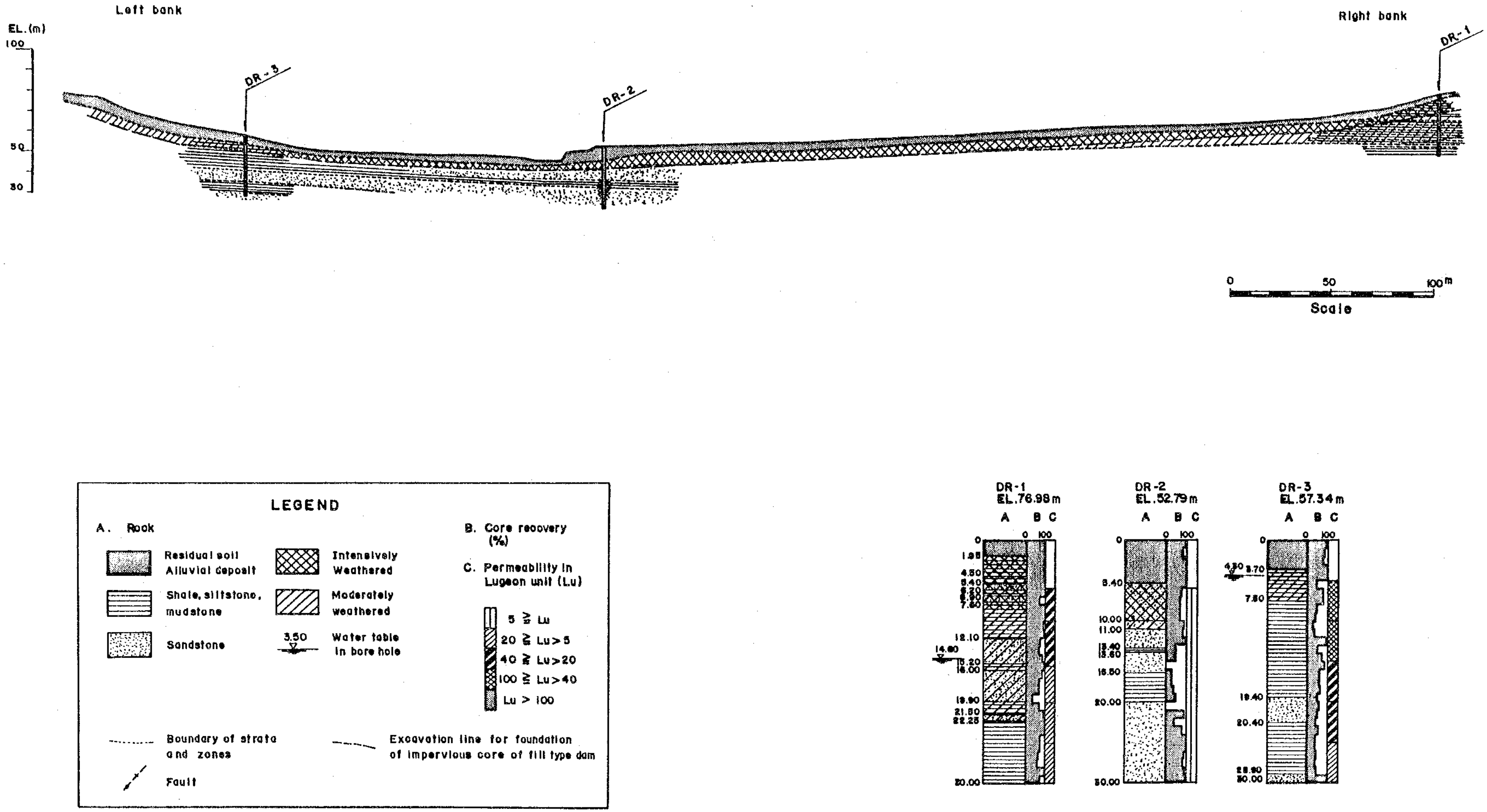
PLATE NO. 6




Geological Profile of Dam Site, Durian

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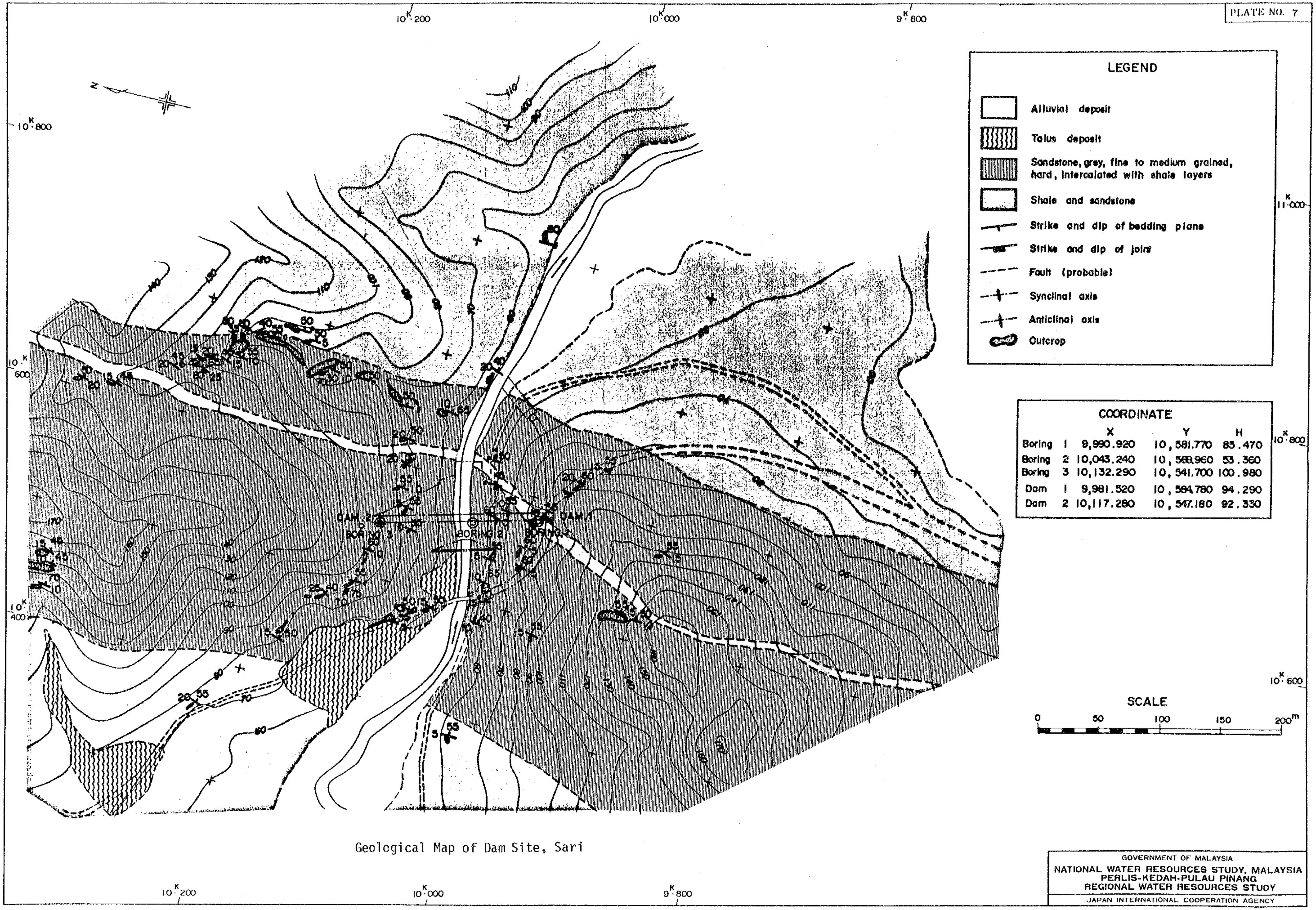
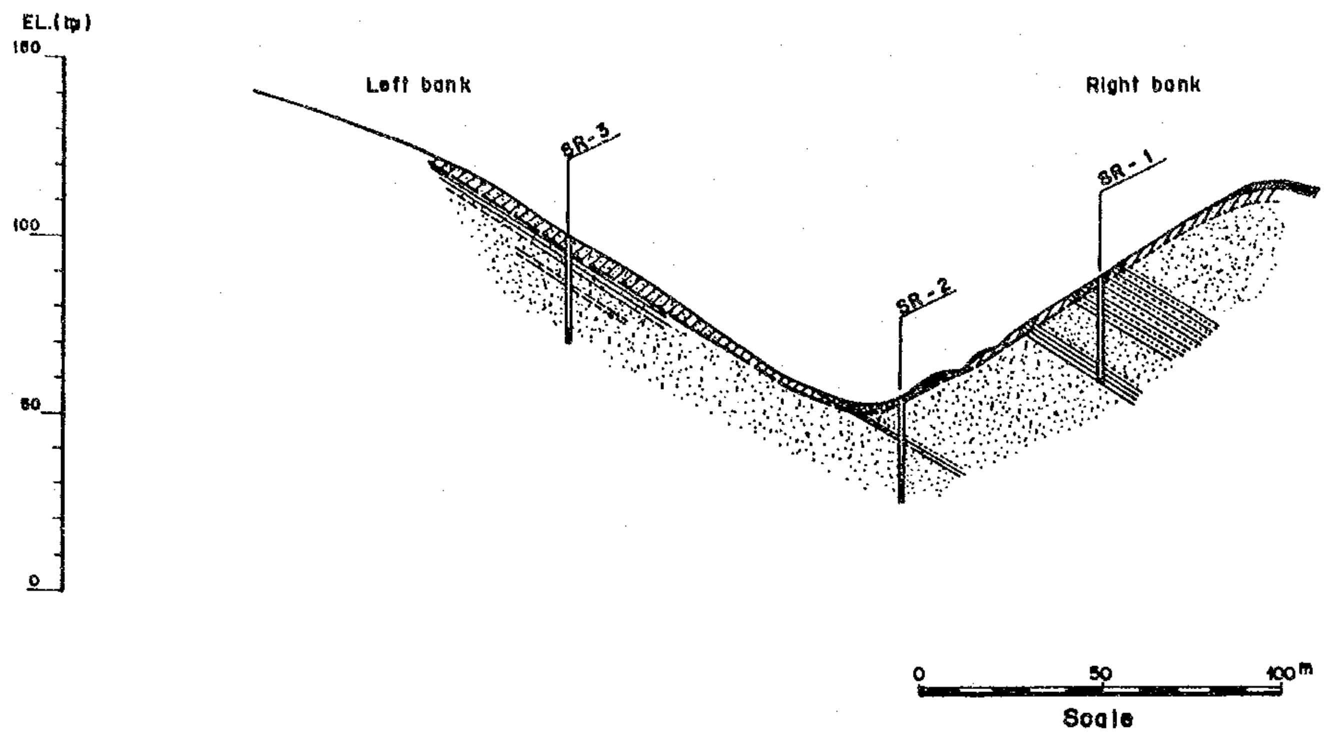
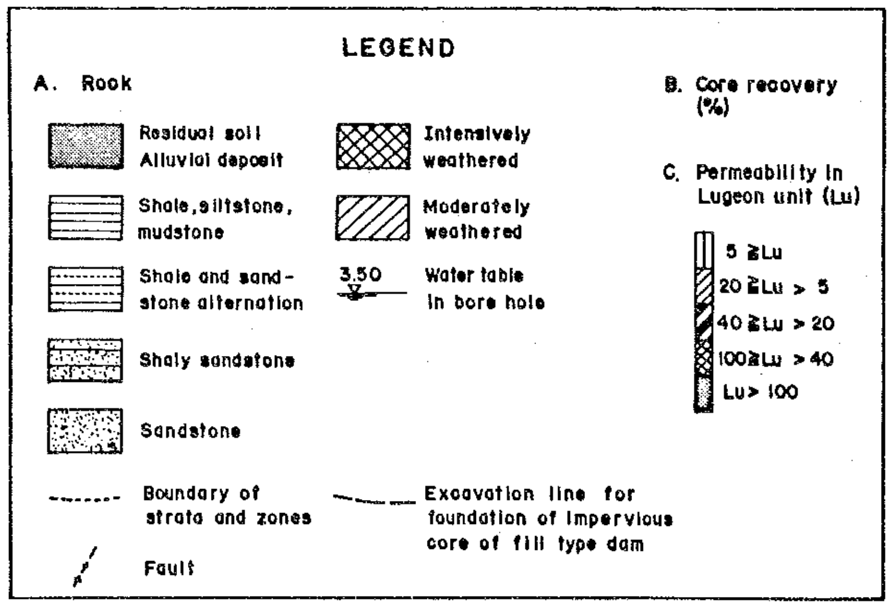
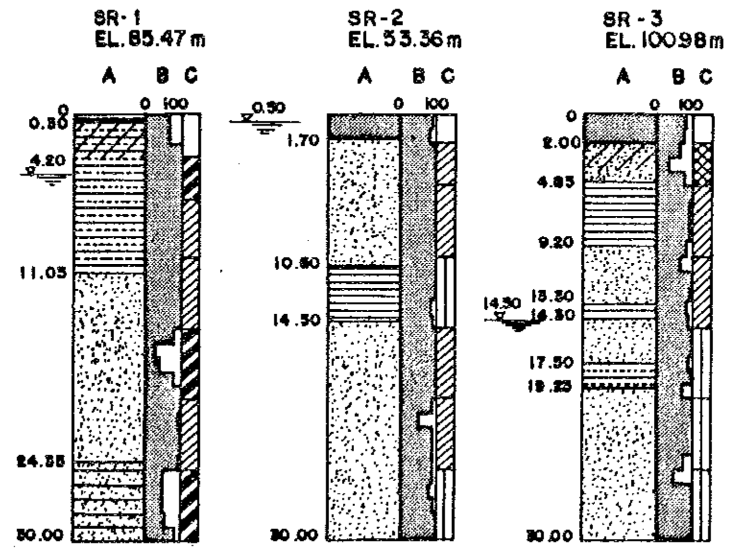



Geological Map of Dam Site, Sari




Geological Profile of Dam Site, Sari

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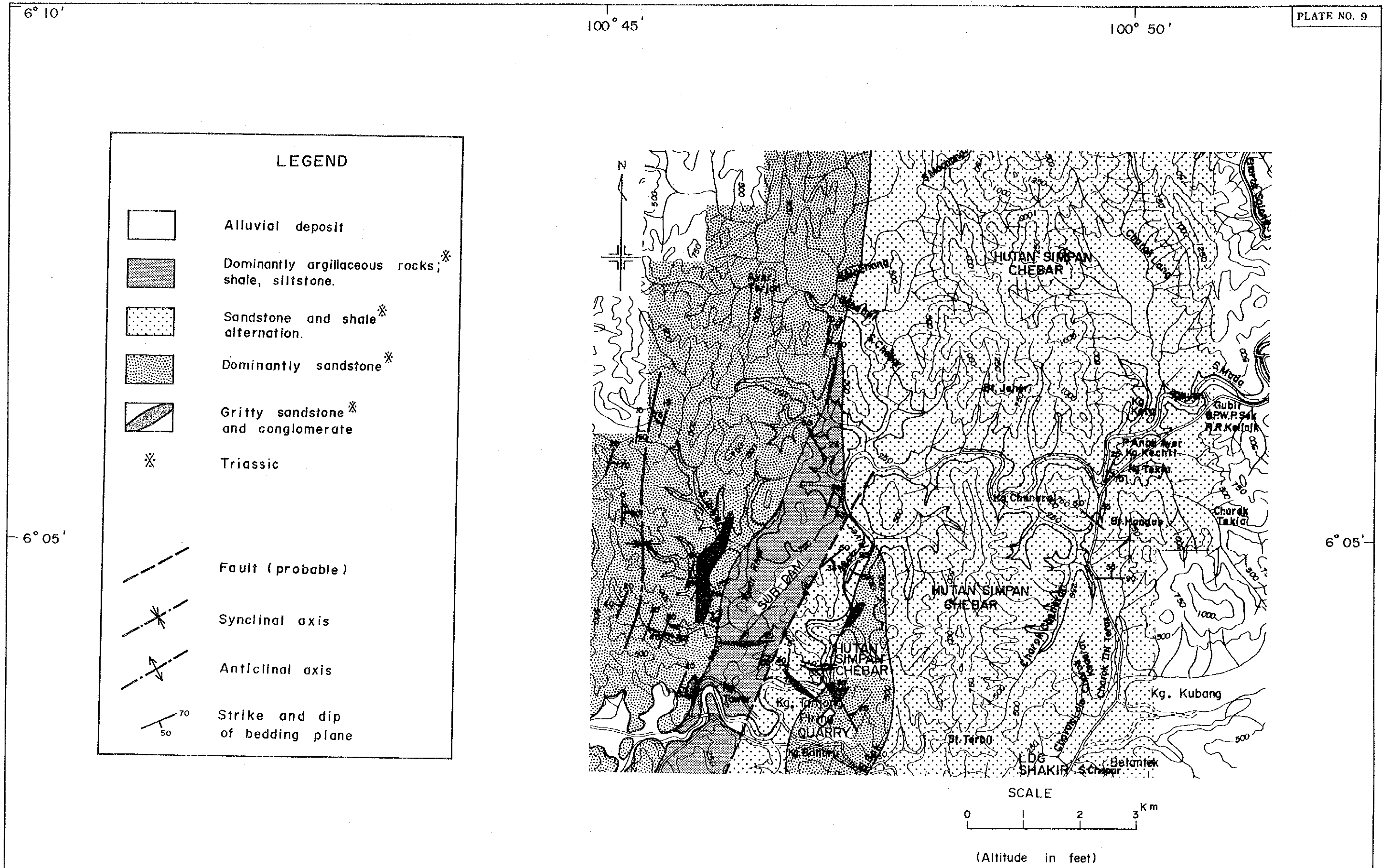
PLATE NO. 9




Geological Map of Dam and Reservoir Area, Tawar-Muda

100° 50'

100° 45'

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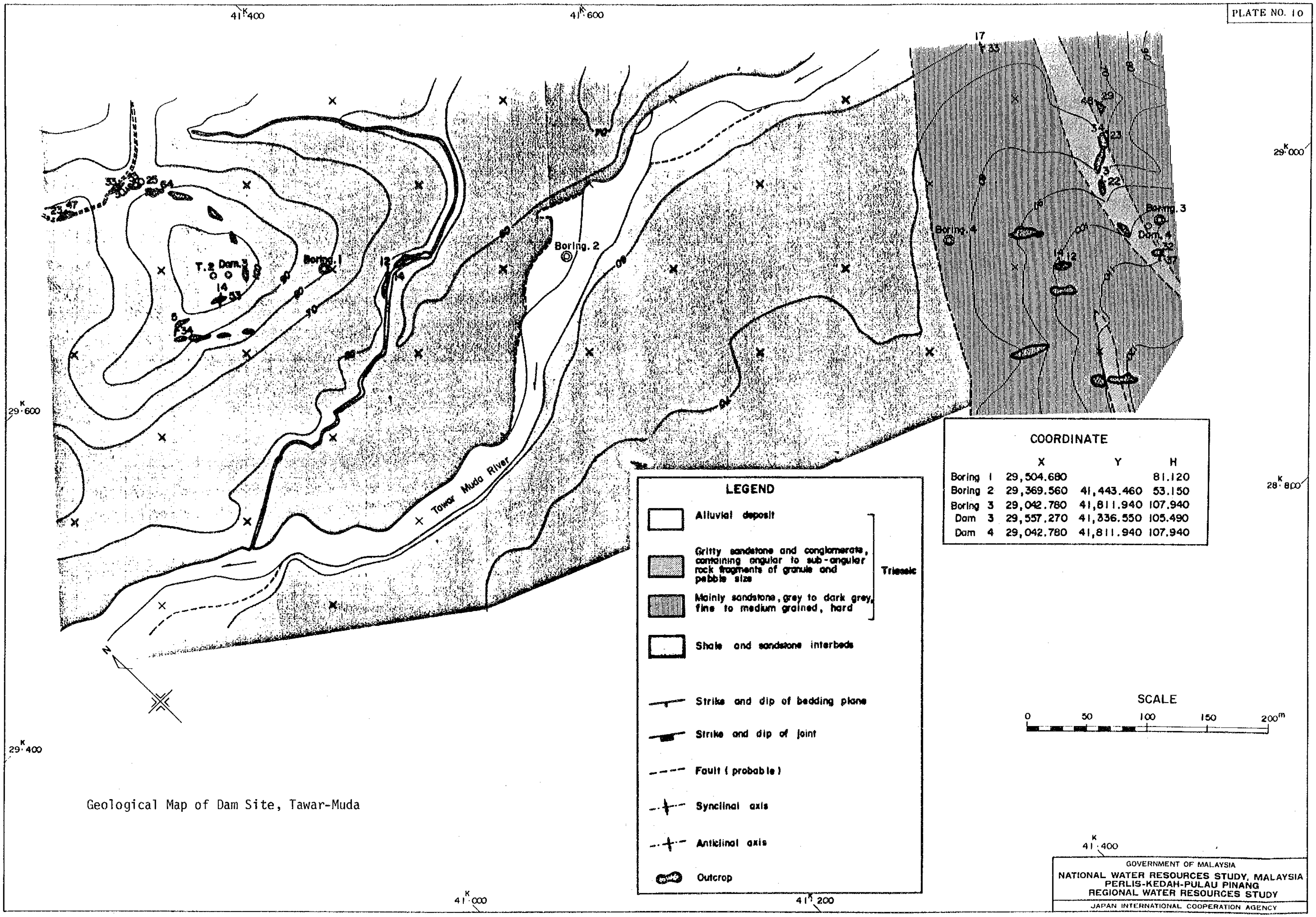
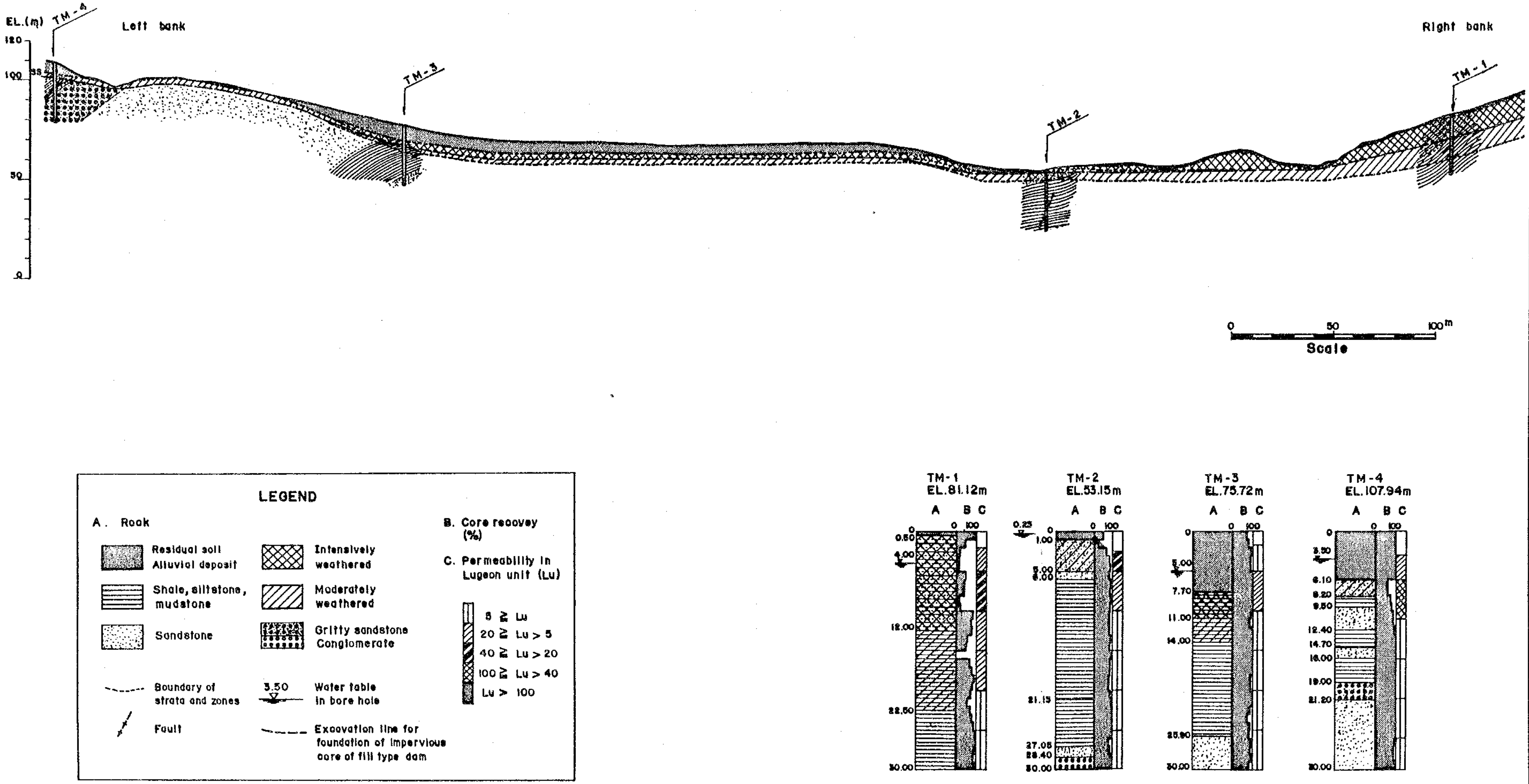
PLATE NO. 10




Geological Map of Dam Site, Tawar-Muda

PLATE NO. 11




Geological Profile of Dam Site, Tawar-Muda Main Dam

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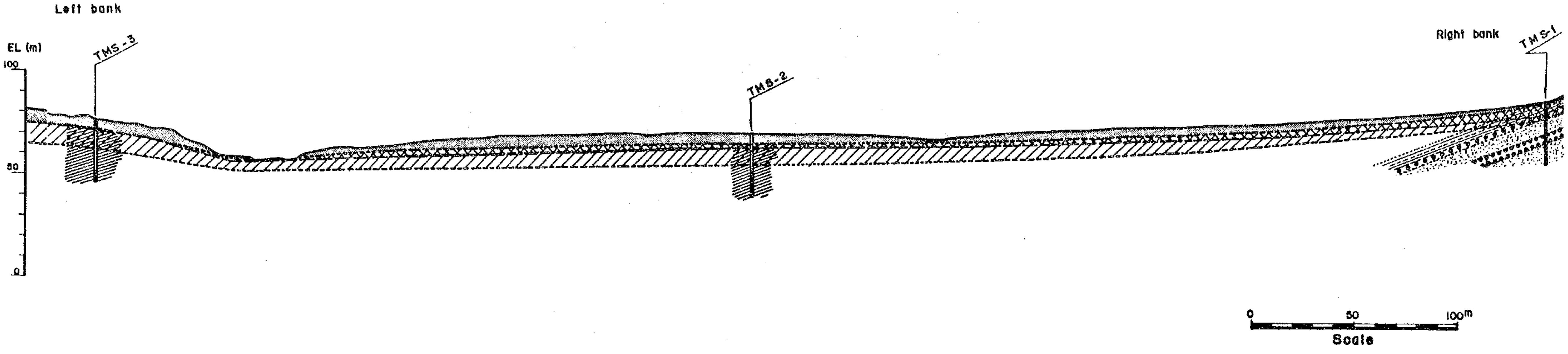
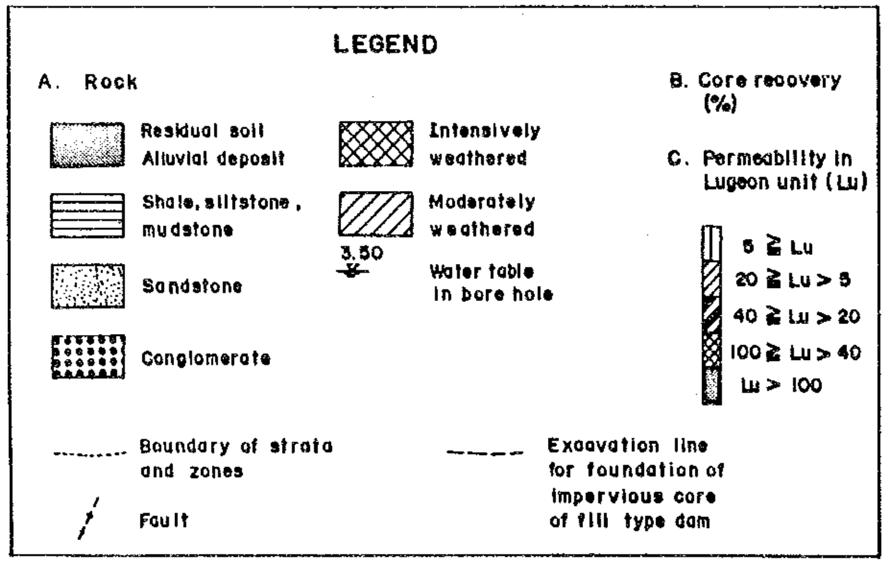
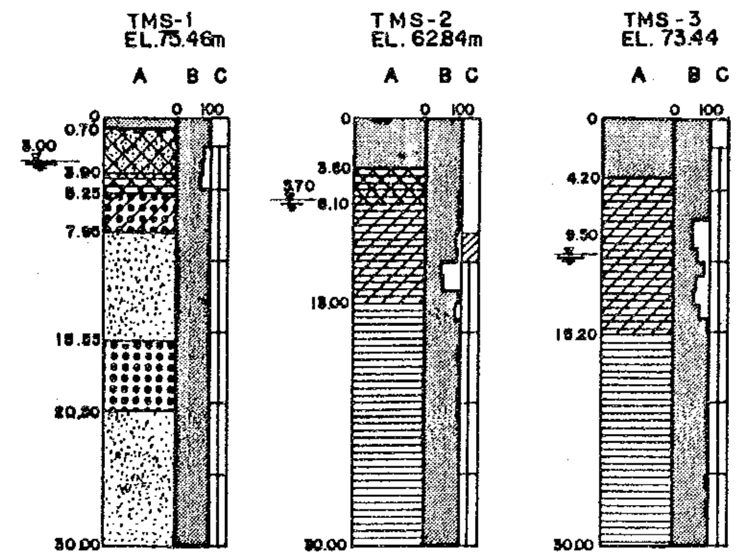
REGIONAL WATER RESOURCES STUDY
JAPAN INTERNATIONAL COOPERATION AGENCY

PLATE NO. 12




Geological Profile of Dam Site, Tawar-Muda Subordinate Dam

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