7.4 Outline of Geology of Project Site

As shown in DWG. 7-3 and 7-4 the bedrock of the project area is composed of the Phu Kradung formation (siltstone, fine-grained sandstone and partly conglomerate) and the Phra Wihan formation (coarse-grained sandstone, claystone, alternation of fine-grained sandstone and siltstone). In terms of hardness of rock, the sandstones and the conglomerate are generally massive and hard while the degree of consolidation of siltstone is slightly low and that of claystone is low.

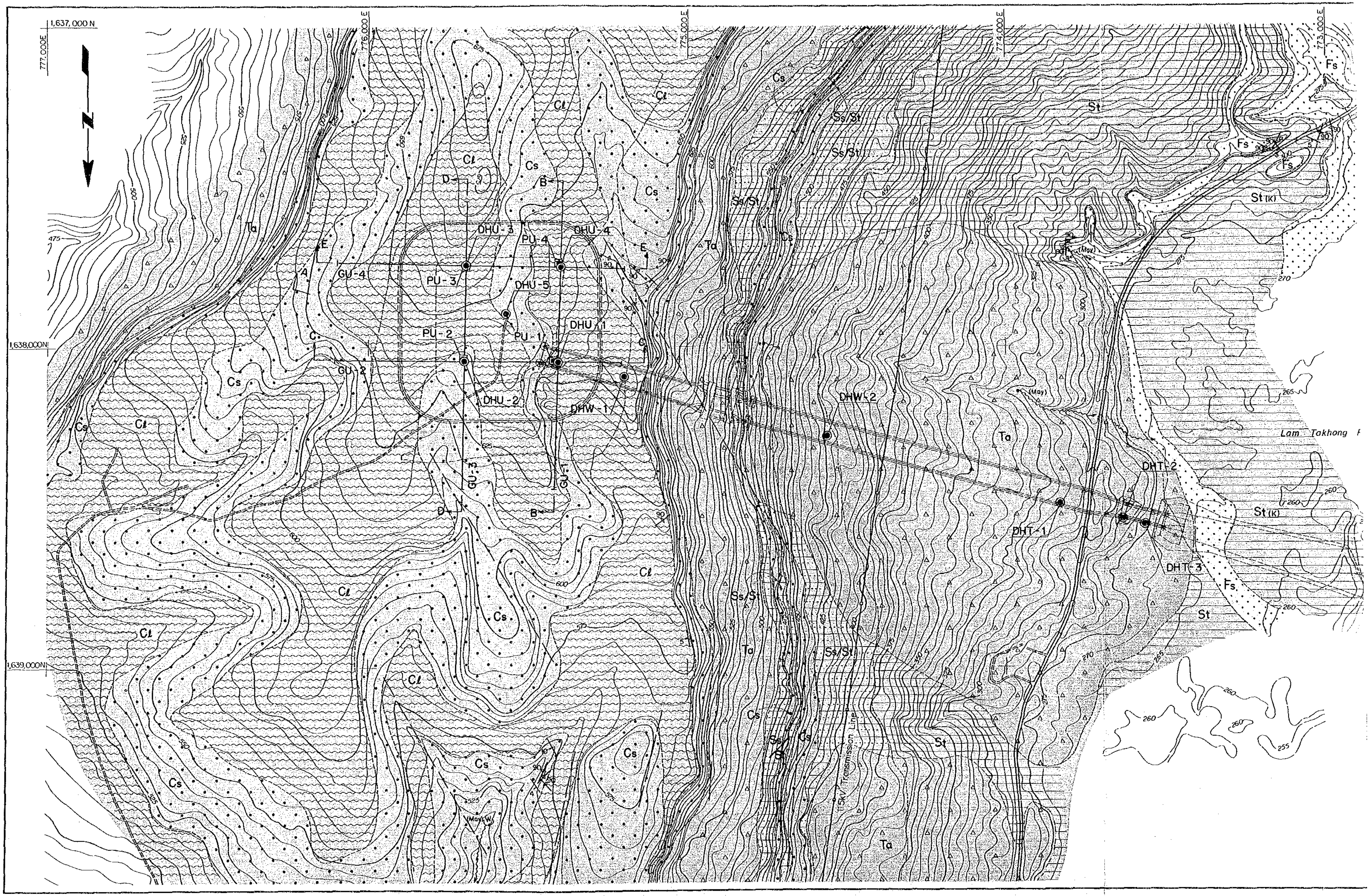
The relations between the layers are conformable and the strikes of the layers are N30°W to N70°W and the dips 5° to 10° (average 6°) NE. Residual soil with a thickness of several meters covers the bedrock at the upper reservoir site. Colluvial deposit and talus deposit which attain 30 m in thickness are distributed in the slope above the waterway tunnel. Table 7-6 shows the stratigraphy of the project area. The thick siltstone layer distributed around the penstock has the possibility of being classified into the Phu Kradung formation which is considered to mainly consists of siltstone, but as it is difficult to make any judgement only from the result of the survey of this area, credit was given to the position of the boundary between formations indicated in the existing literature and this layer was classified into the Phra Wihan formation.

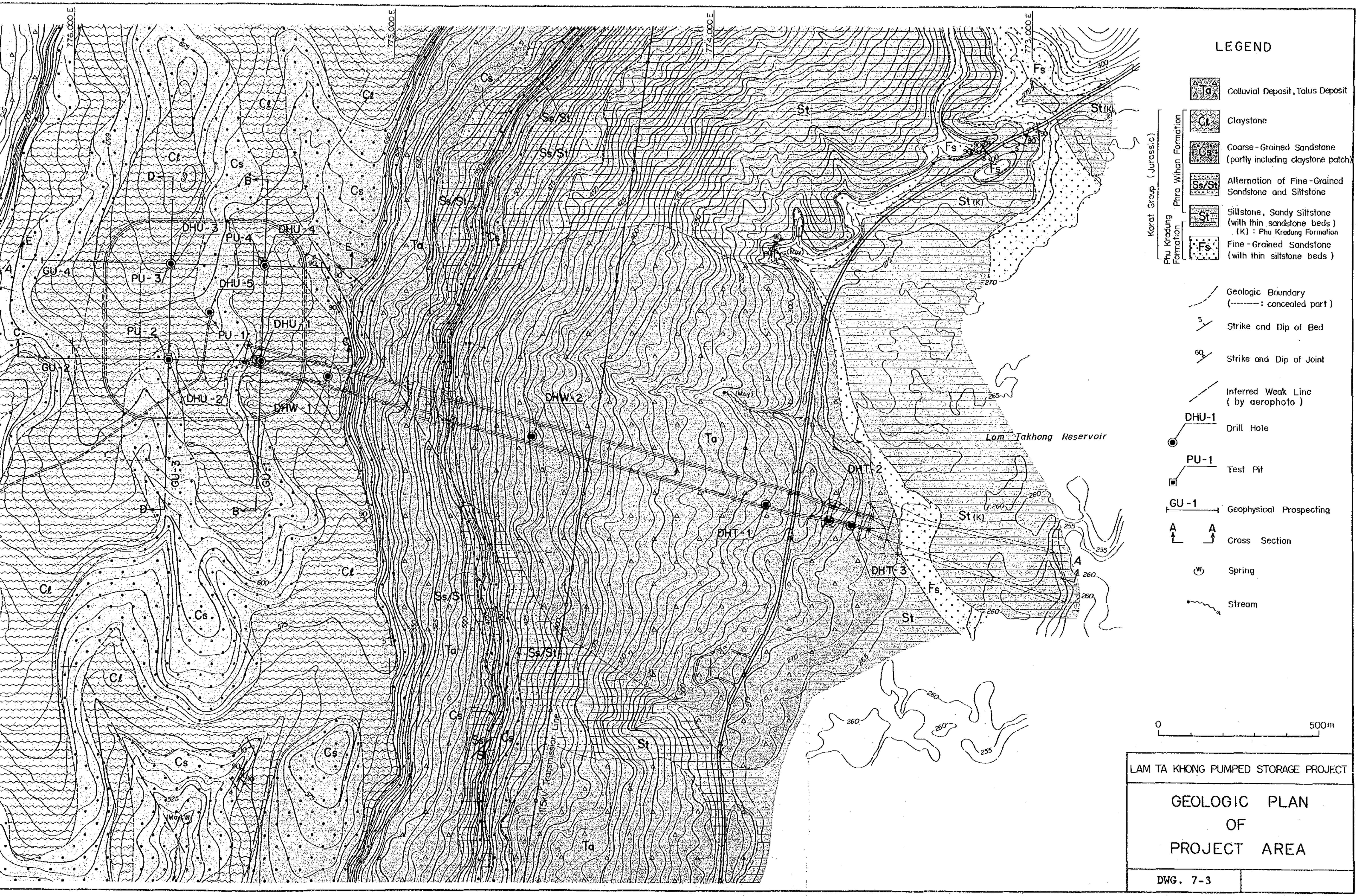
In this area no fault was found in the outcrop, however, the drilling resulted in small-scaled faults being found. Also, in aerophotographs several lineaments which may indicate the existence of faults could be found.

Table 7-6 shows outlines of the bedrocks constituting the project sites and the values of physical properties resulting from the test. Logs of drill holes are attached in Appendix-A.

Table 7-6 Stratigraphy and Properties of Rocks in Project Area

Era	Period	Formation (Geologic Unit)		Lithology	Thickness (m) Unit bed	Thickness (m) Total	Distribution	Compressive Strength (kgf/cm^2)	Deformation Modulus (kgf/cm^2)	Remarks
CENOZOIC	Quaternary	Colluvial Deposit Talus Deposit		Sandstone fragments and soil material: poorly sorted, including boulders	—	0~30	Slope over waterway	—	—	
		Residual Soil		Lateritic red soil: silty gravel~sandy clay rich in oxides of iron	—	0~ 4	Upper Reservoir	—	—	N-value:50<
MESOZOIC	Jurassic	Phra Wihan Formation	upper part	Claystone: Massive, light-gray, silty	5<, 5-15, 1-3	60<	Upper Reservoir	20-30	—	weathered
				Medium to coarse-grained sandstone: weakly laminated, light-gray, quartzose, partly including claystone patch	25, 30-40		Upper Reservoir, Intake	500-800	10,000-60,000	weathered RQD = 66 %
			middle part	Alternation of sandstone and siltstone: Fine-grained sandstone; light-gray, calcareous, Siltstone and sandy siltstone; Reddish-purple to greenish-gray, calcareous	—	200	Headrace, Penstock	Fine-grained sandstone 500-1,100 Siltstone 200-300	Fine-grained sandstone 50,000-80,000 Siltstone 11,000-25,000	fresh RQD = 75 %
				Medium to coarse-grained sandstone: weakly laminated, light-gray, quartzose	5, 25			700-800	50,000 -300,000<	fresh RQD = 92 %
			lower part	Siltstone and sandy siltstone: Reddish-purple to greenish-gray, calcareous, intercalated light-gray fine-grained calcareous sandstone	—	180	Penstock, Powerhouse	200-300 (sandy part : 500-800)	11,000-25,000	fresh RQD = 79 %
		Phu Kradung Formation		Siltstone and sandy siltstone: Reddish-purple to greenish-gray, calcareous	—	130<	Powerhouse, Tailrace, Outlet	200-300 (sandy part : 500-800)	1,500-25,000	partly weathered RQD = 86 %
				Fine-grained sandstone: light-gray, calcareous, locally intercalated greenish-gray very coarse-grained sandstone and conglomerate	2-20, 20, 10			700-1,100	9,000-80,000	partly weathered RQD = 79 %

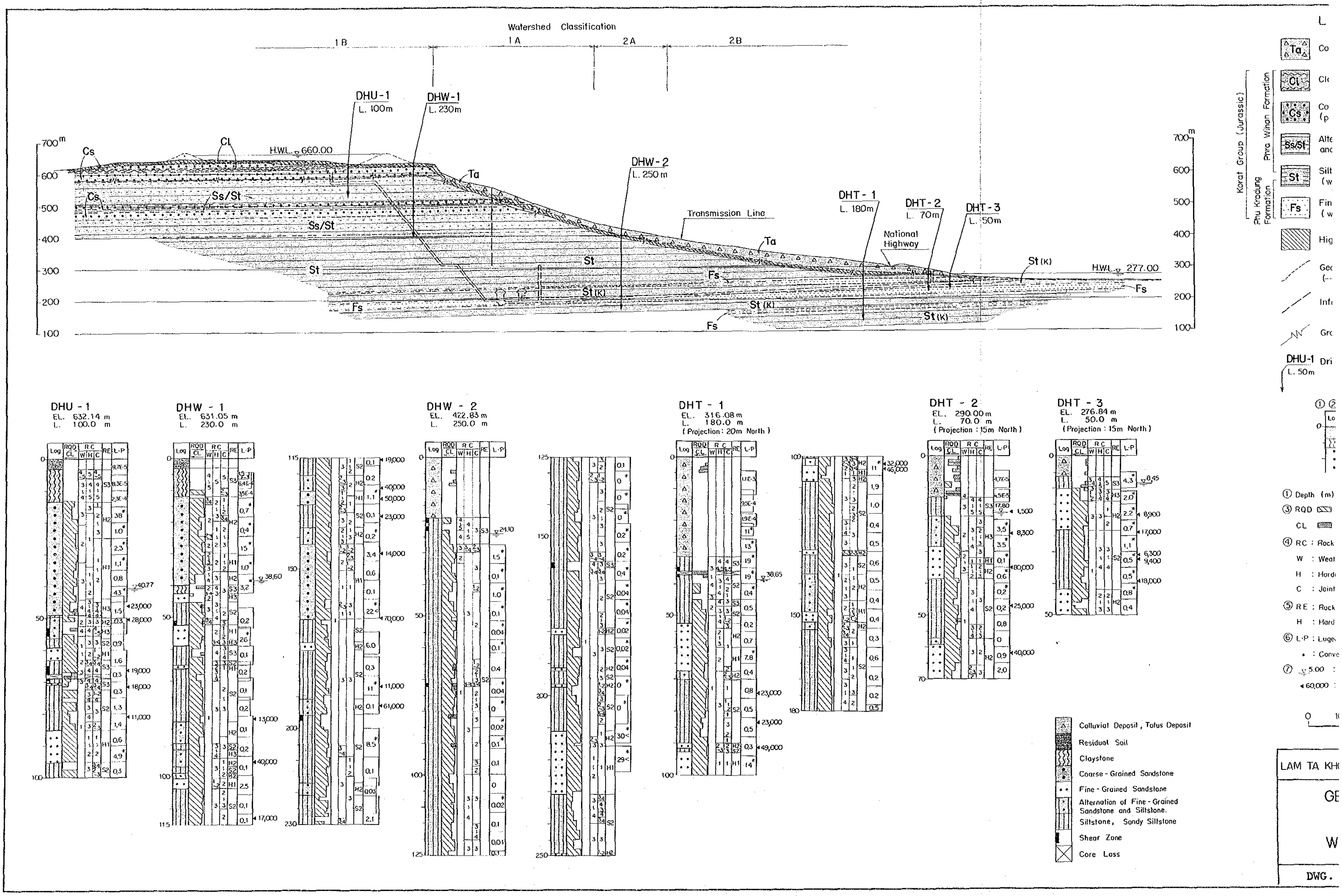

1,637,000 N
777,000E
776,000 E
775,000 E
774,000 E
773,000 E
1,638,000N
1,639,000N
N
DHU-3
DHU-4
DHU-5
DHU-1
DHU-2
PU-1
PU-2
PU-3
PU-4
GU-1
GU-2
GU-3
GU-4
DHW-1
DHW-2
DHT-1
DHT-2
DHT-3
Lam Takhong
115kV Transmission Line
Ta
Cs
Cℓ
Ss/St
St
St (K)
Fs
(May)
(May-W)



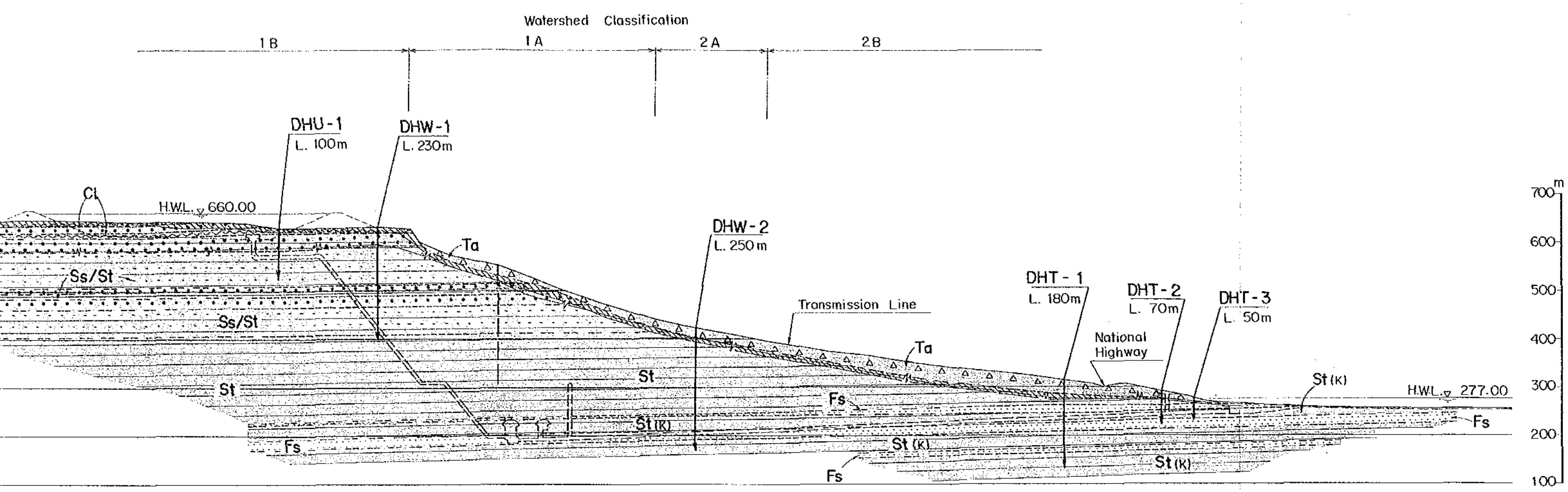
LAM TA KHONG PUMPED STORAGE PROJECT

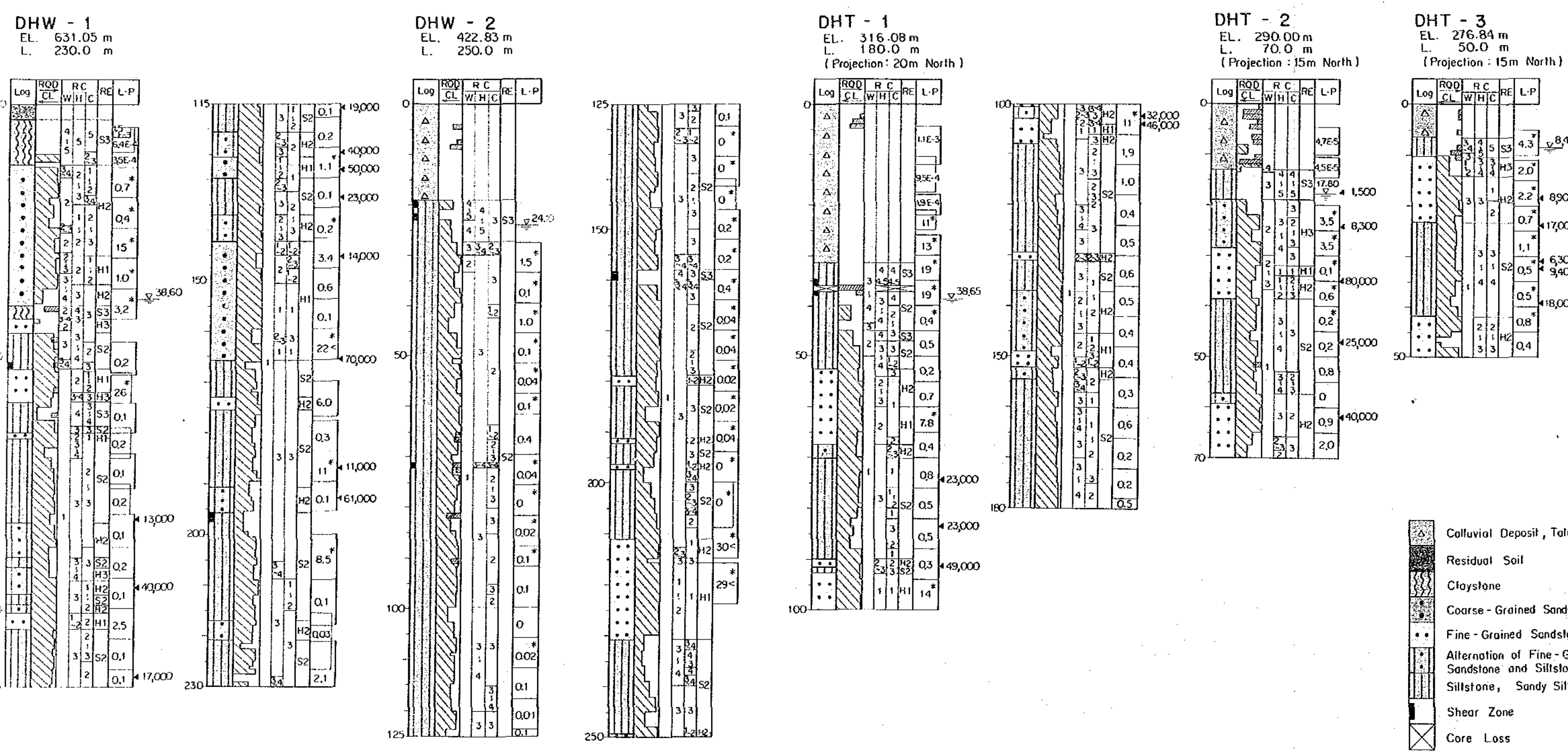
GEOLOGIC PLAN OF PROJECT AREA

DWG. 7-3



Watershed Classification
1 B
1 A
2 A
2 B
DHU-1
L. 100m
DHW-1
L. 230m
DHW-2
L. 250m
DHT-1
L. 180m
DHT-2
L. 70m
DHT-3
L. 50m
H.W.L. 660.00
H.W.L. 277.00
Cs
Cl
Ss/St
Ta
St
St (K)
Fs
Transmission Line
National Highway
Korat Group (Jurassic)
Phra Wihan Formation
Phu Kradung Formation
DHU-1
EL. 632.14 m
L. 100.0 m
DHW-1
EL. 631.05 m
L. 230.0 m
DHW-2
EL. 422.83 m
L. 250.0 m
DHT-1
EL. 316.08 m
L. 180.0 m
(Projection : 20m North)
DHT-2
EL. 290.00 m
L. 70.0 m
(Projection : 15m North)
DHT-3
EL. 276.84 m
L. 50.0 m
(Projection : 15m North)
Log
RQD
CL
RC
W H C
RE
L-P
Colluvial Deposit , Talus Deposit
Residual Soil
Claystone
Coarse - Grained Sandstone
Fine - Grained Sandstone
Alternation of Fine - Grained Sandstone and Siltstone.
Siltstone, Sandy Siltstone
Shear Zone
Core Loss
① Depth (m)
③ RQD
CL
④ RC : Rock
W : Weat
H : Hard
C : Joint
⑤ RE : Rock
H : Hard
⑥ L-P : Luge
• : Conve
LAM TA KH
GE
W
DWG.





Colluvial Deposit, Talus Deposit
Residual Soil
Claystone
Coarse-Grained Sandstone
Fine-Grained Sandstone
Alternation of Fine-Grained Sandstone and Siltstone.
Siltstone, Sandy Siltstone
Shear Zone
Core Loss

LEGEND

Korat Group (Jurassic)

Phra Wihan Formation

- Ta — Colluvial Deposit, Talus Deposit
- Cl — Claystone
- Cs — Coarse-Grained Sandstone (partly including claystone patch)
- Ss/St — Alternation of Fine-Grained Sandstone and Siltstone

Phu Kradung Formation

- St — Siltstone, Sandy Siltstone (with thin fine-grained sandstone beds) (K): Phu Kradung Formation
- Fs — Fine-Grained Sandstone (with thin siltstone beds)

Highly Weathered Rock (W ≧ 3~4)

Geologic Boundary (-- -- --: inferred)

Inferred Weak Line (by aerophoto)

Ground Water Table

DHU-1 L. 50m — Drill Hole — E.L. : Elevation; L. : Length

① ② ③ ④ ⑤ ⑥ ⑦

① Depth (m) ② Geologic Column

③ RQD : Rock Quality Designation (%)

CL : Core Loss (%)

④ RC : Rock Classification

W : Weathering, 1 (very fresh) ~ 5 (extremely weathered)

H : Hardness, 1 (very hard) ~ 5 (soft)

C : Joint Interval, 1 (over 30cm) ~ 5 (under 1cm)

⑤ RE : Rock Evaluation

H : Hard Rock, S : Soft Rock, 1 (good) ~ 3 (bad)

⑥ L-P : Lugeon Value (Lu) or Permeability Coefficient (cm/s)

* : Converted Lugeon Value, E-6 : $\times 10^{-6}$

⑦ ▽5.00 : Final Water Level (m)

◀60,000 : Deformation Modulus (kgf/cm²)

0 100 200 300 400 500 m

LAM TA KHONG PUMPED STORAGE PROJECT

GEOLOGIC PROFILE OF WATERWAY (A-A)

DWG. 7-4

7.5 Geology of Upper Reservoir Site

7.5.1 Topography

The upper reservoir is located on a gentle slope of the top of the plateau ranging in altitude from about 600 to 675 m. Since there is a valley to the east of the upper reservoir the width of the top of the plateau in this area is about 1.3 km. The top of the plateau is high in the center and presents a mild ridge-shaped landform. 4 small valleys (flowing water is found only immediately after a rainfall) run to northeast or northwest. The slopes are inclined east-, north- or westward within the range of about 3° to 15° and the top of the plateau is wholly inclined 5° northeastward.

The maximum depth of excavation is about 40 m in the southeast part. The maximum height of the dam is about 50 m in the northwest part.

In the northern part of the upper reservoir there is a lineament interpreted by aerophotographs as running from northwest to southeast, but at the site this landform is not clear. At this location there is no other landform that will be a problem such as lineament or landform susceptible to a landslide.

7.5.2 Geology

The surface of the plateau which is projected for the upper reservoir shows residual soil distributed mainly and only a few sporadic outcrops of coarse-grained sandstone. The geology of the upper reservoir site that has been clarified on the basis of the results of the survey of these outcrops, the drilling and the seismic prospecting is shown in DWG. 7-3, 7-4 and 7-5.

The geology of this site consists of the Phra Wihan formation of coarse-grained sandstone, claystone, alternation of fine-grained sandstone and siltstone as well as residual soil that covers these bedrocks.

(1) Bedrock

The bedrock consists, from the bottom to the top, of an alternation of fine-grained sandstone and siltstone (thickness: about 80 m), a layer of claystone (thickness: about 1 to 3 m), a layer of coarse-grained sandstone (thickness: about 30 to 40 m), a layer of claystone (thickness: about 0 to 15 m) and a layer of coarse-grained sandstone (thickness: about 25 m). The alternation of fine-grained sandstone and siltstone consists of irregularly alternated beds of grayish white-colored medium-to-fine-grained quartzose sandstone and reddish purple-to-greenish gray-colored siltstone with a thickness of several tens of centimeters to several meters. Rocks of intermediate character such as silty sandstone and sandy siltstone are also found. As for the hardness of the rocks, the sandstones are massive and hard while the silt-stone has a little low degree of consolidation and is a little soft. The claystone has a grayish white color and a low degree of cementation and is soft. The coarse-grained sandstone mainly consists of medium-to-coarse quartz grains and is well-cemented, hard and massive without clear bedding planes. This layer also partly contains patches of grayish-white-colored claystone (the above-mentioned lower layer of claystone) ranging in size from several millimeters to several tens of centimeters. This kind of sedimentary structure is thought to have been formed a small-scaled slumping developed when claystone had consolidated to some extent after its deposition. There are two layers of coarse-grained sandstone of an almost similar nature, the lower one being continuously distributed over an extensive area thereby forming steep cliffs around the plateau and the upper one forming the ridge on the top of the plateau.

The strata have strikes of N30° to 70°W and dips of 5° to 10° (average about 6°) NE. Lateral lithologic changes are small in general although they are a little remarkable partly in the layer of claystone and coarse-grained sandstone, and each layer is continuously distributed.

(2) Fault and Joint

During the survey of the surface no fault was found at all even at the place where the lineaments pass. Although the drilling resulted in a small fault shear zone being found in alternation of fine-grained sandstone and siltstone, no clear fault could be found in the coarse-grained sandstone and claystone. From the result of seismic prospecting, either, no fault is assumed to exist. From the continuity of the layers, too, there appears to be a low possibility of a large fault existing.

Fig. 7-1 shows the result of calculation of average joint frequency in each layer. In this figure the joints observed in drill cores (see Appendix-A) are divided into 6 classes on the basis of the dip of joint planes which is divided into 15 degree periods. Joint frequency is expressed by the joint number in the rock mass of diameter 10 m and is calculated by the following equation:

$$N_{10} = \frac{N_J}{L \cos\theta} \times 10 \qquad \theta = \frac{a + b}{2}$$

where, N_{10} : number of joints of dip a $\sim$ b ° in the rock mass of diameter 10 m

N_J : number of joints of dip a $\sim$ b ° in drill cores

L : the length of drill cores (m)

θ : dip of joint plane (°)

The feature of the joints in claystone and coarse-grained sandstone which are the main foundation rocks of the upper reservoir is summarized as follows:

- Clear joints are rare in claystone. The total frequency of all joints is about 5 joints/10 m.

- The joint spacing of coarse-grained sandstone is generally 1 to several meters, although it is partly less than several tens of joints near the ground surface formed by weathering. The total frequency of all joints is about 11 joints/10 m.

- The joints observed in outcrops and drill cores are divided into the following three types:

  (a) Very low-angle joint with a dip of 5 $\sim$ 15° (close to the dip of the bedding plane)
  (b) Low to medium-angle joint with a dip of 15 $\sim$ 60°
  (c) High-angle joint with a dip of 60 $\sim$ 90°

  In coarse-grained sandstone a-type joint (along the bedding plane) and b-type joint (nearly perpendicular to the bedding plane) are dominant.

- At this site no joint with a mineral vein was found.

(3) Weathering

The rock near the ground surface is weathered into brown color and softened. The highly weathered part with a few parts remaining un-weathered has a maximum depth of about 20 m and the slightly weathered part with brown cracks has a maximum depth of about 70 m. The degree of weathering does not simply decrease as the depth increases. Highly weathered rock is also distributed in the deep part, which is though to be attributable to the effect of ground water of which the level is located near the lower boundary of the lower layer of the coarse-grained sandstone as described later.

(4) Surface Deposit

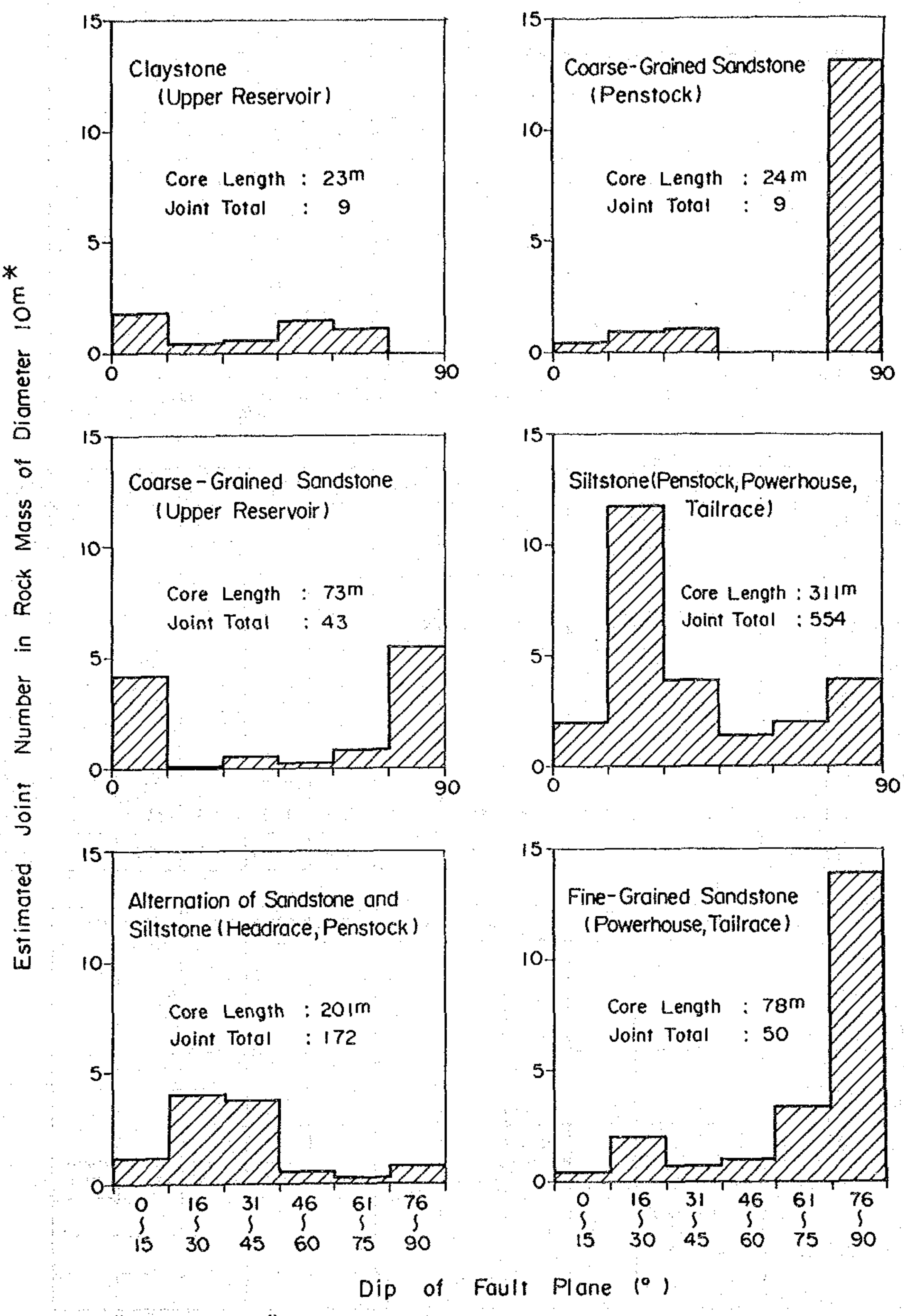
At this site, except for some parts where coarse-grained sandstone is exposed, there is a wide distribution of residual solid of reddish-brown color with a thickness of 3 to 4 m that covers the bedrock. This residual soil is so-called "laterite" which is classified in Unified Soil Classification into silty gravel (GM). The gravel consists of hematite and extremely weathered sandstone.

In the small gullys on the plateau there is no distribution of alluvial deposit.

(5) Ground Water Level

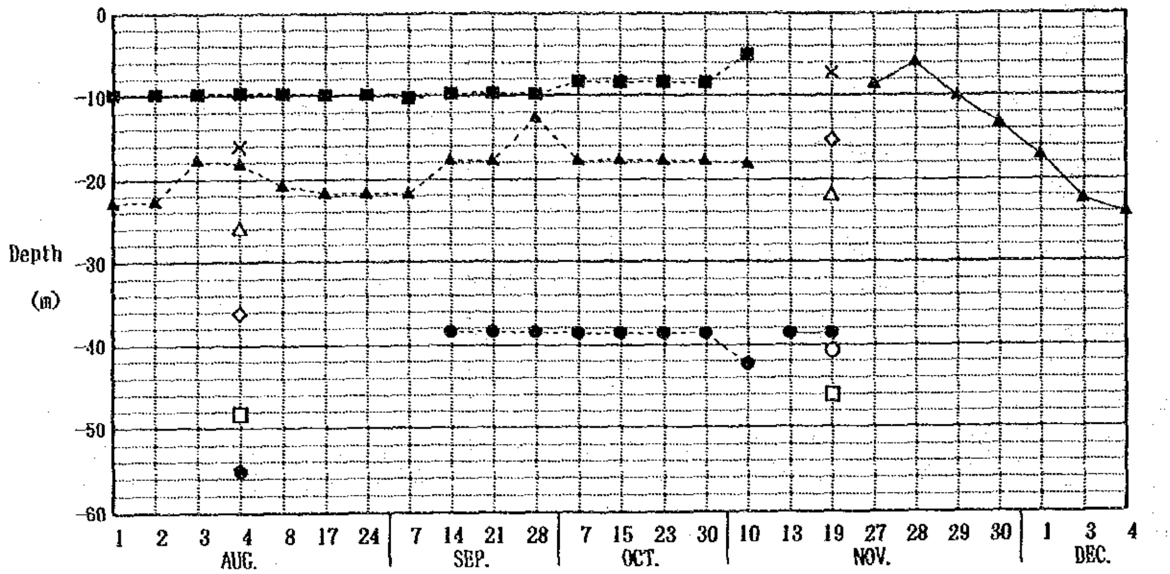
On the plateau where the upper reservoir is projected there is a spring at an altitude of about 515 m along the valley located about 1.5 km to the north of the upper reservoir. Downstream of this spring there is a continuous water flow. This spring according to the information of an neighboring inhabitant never goes dry throughout the year. At this point the lower part of the lower layer of coarse-grained sandstone is distributed. Although surface water is also found at a pond in the upper reservoir site and at the earth dam (height: about 7 m, length: about 70 m) near a village about 1.5 km to the northeast of the upper reservoir site, this is a temporary accumulation of rain water that goes dry during the dry season.

The water levels in the drill holes obtained by drilling conducted at the upper reservoir are shown in DWG. 7-4, 7-5 and Fig. 7-2. From these results the ground water level around the upper reservoir is thought to be located near the lower boundary of the lower layer of coarse-grained sandstone (depth: 20 ~ 50 m). (The water levels in the drill holes DHU-2 and 5 is judged not to indicate a true one from the geologic conditions of the bedrock and from the distribution of the surrounding ground water levels.) These data were obtained by measurements during the rainy season and it is thought to be necessary to measure the water levels over a long period of time during the dry season from now on.



* "Joint Numbers" can be calculated from true average joint spacing.

Fig. 7-1 Frequency of Joints in Each Layer Estimated from Joints in Drill Cores

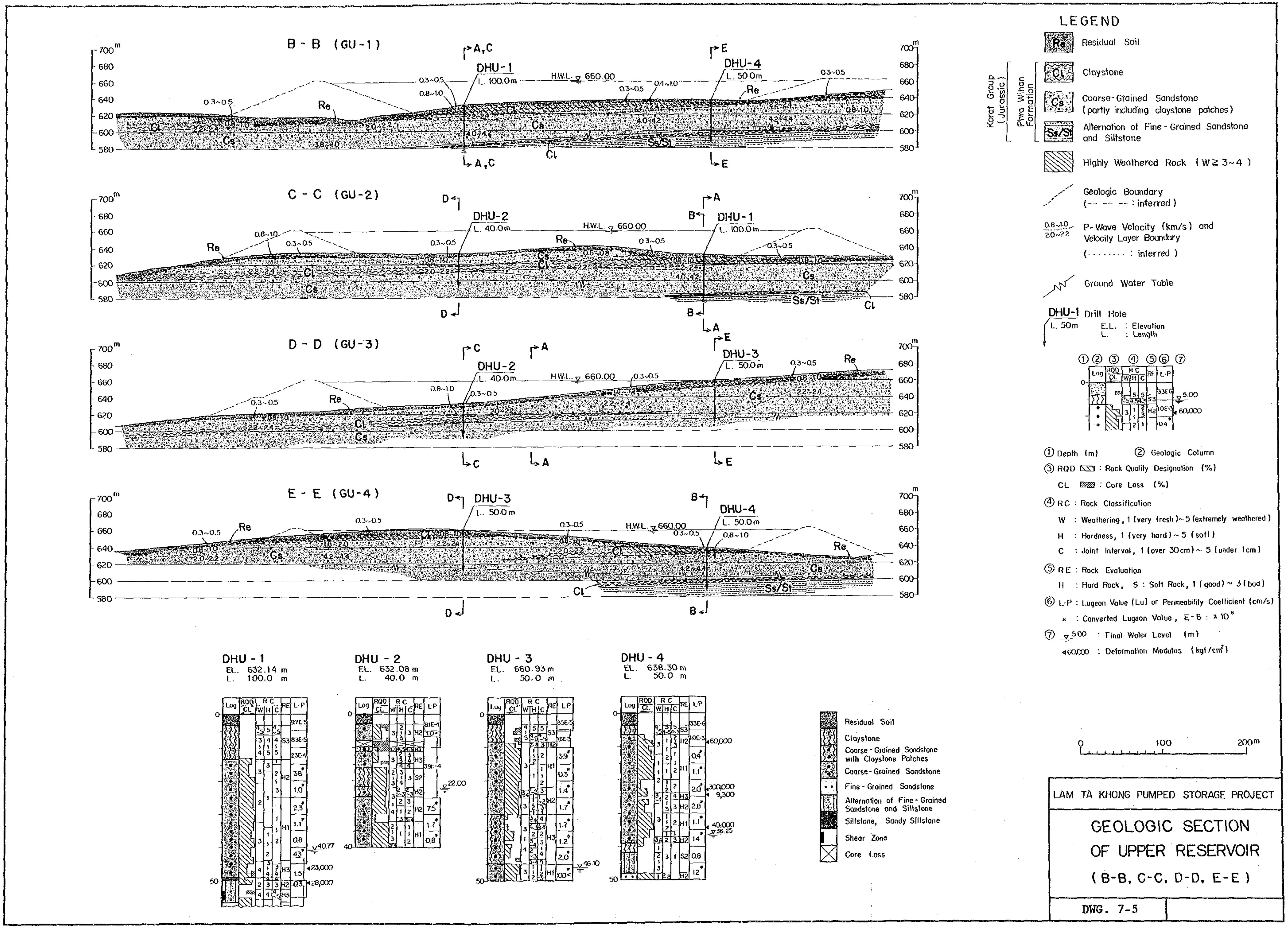


DATE	AUG. 1	AUG. 2	AUG. 3	AUG. 4	AUG. 8	AUG. 17	AUG. 24	SEP. 7	SEP. 14	SEP. 21	SEP. 28	OCT. 7	OCT. 15
DHU-1 —○													
DHU-2 —△				-26.0									
DHU-3 —□				-48.3									
DHU-4 —◇				**-36.25**									
DHU-5 —×				-16.05*									
DHW-1 —●				-55.2									
DHW-2 —▲													
DHT-1 ···●									-38.4	-38.45	-38.5	-38.6	-38.6
DHT-2 ···▲	-22.8	-22.65	-17.7	-18.2	-20.8	-21.7	-21.7	-21.8	-17.7	-17.8	-12.7*	-17.8	-17.75
DHT-3 ···■	-9.8	-9.8	-9.8	-9.7	-9.75	-9.9	-9.9	-10.3	-9.75	-9.7	-9.8	-8.3	-8.4

DATE	OCT. 23	OCT. 30	NOV. 10	NOV. 13	NOV. 19	NOV. 27	NOV. 28	NOV. 29	NOV. 30	DEC. 1	DEC. 3	DEC. 4
DHU-1 —○					**-40.8**							
DHU-2 —△					**-22.0**							
DHU-3 —□					**-46.1**							
DHU-4 —◇					-15.4*							
DHU-5 —×					-7.3*							
DHW-1 —●				-38.6	**-38.6**							
DHW-2 —▲						-8.6	-6.0	-10.1	-13.3	-17.2	-22.5	**-24.1**
DHT-1 ···●	-38.6	**-38.65**	-42.4									
DHT-2 ···▲	-17.8	**-17.8**	-18.2									
DHT-3 ···■	-8.4	**-8.45**	-5.1									

* : unreliable data □ : final water level

Fig. 7-2 Water Level in Drill Holes


B - B (GU-1)
C - C (GU-2)
D - D (GU-3)
E - E (GU-4)
DHU-1
L. 100.0m
DHU-2
L. 40.0m
DHU-3
L. 50.0m
DHU-4
L. 50.0m
H.W.L. 660.00
LEGEND
Residual Soil
Korat Group (Jurassic)
Phra Wihan Formation
Claystone
Coarse-Grained Sandstone (partly including claystone patches)
Alternation of Fine-Grained Sandstone and Siltstone
Highly Weathered Rock (W≧3~4)
Geologic Boundary
(-- -- -- : inferred)
P-Wave Velocity (km/s) and Velocity Layer Boundary
(........ : inferred)
Ground Water Table
Drill Hole
E.L. : Elevation
L. : Length
① Depth (m)
② Geologic Column
③ RQD : Rock Quality Designation (%)
CL : Core Loss (%)
④ RC : Rock Classification
W : Weathering, 1 (very fresh) ~ 5 (extremely weathered)
H : Hardness, 1 (very hard) ~ 5 (soft)
C : Joint Interval, 1 (over 30cm) ~ 5 (under 1cm)
⑤ RE : Rock Evaluation
H : Hard Rock, S : Soft Rock, 1 (good) ~ 3 (bad)
⑥ L-P : Lugeon Value (Lu) or Permeability Coefficient (cm/s)
* : Converted Lugeon Value, E-6 : x 10^-6
⑦ Final Water Level (m)
Deformation Modulus (kgf/cm²)
DHU - 1
EL. 632.14 m
L. 100.0 m
DHU - 2
EL. 632.08 m
L. 40.0 m
DHU - 3
EL. 660.93 m
L. 50.0 m
DHU - 4
EL. 638.30 m
L. 50.0 m
Residual Soil
Claystone
Coarse-Grained Sandstone with Claystone Patches
Coarse-Grained Sandstone
Fine-Grained Sandstone
Alternation of Fine-Grained Sandstone and Siltstone
Siltstone, Sandy Siltstone
Shear Zone
Core Loss
0 100 200m
LAM TA KHONG PUMPED STORAGE PROJECT
GEOLOGIC SECTION OF UPPER RESERVOIR (B-B, C-C, D-D, E-E)
DWG. 7-5

7.6 Geology of Waterway Route

7.6.1 Topography

The intake is projected at a site with an elevation of about 640 m at a distance of about 300 m from the west end of the plateau. The inclination of the surface in and around this site is about 10°. The headrace extends at a depth about 70 m under the flat surface of the plateau to a place at a distance of about 200 m from the west end of the plateau.

The penstock passes under the plateau, the approximately 30 m high steep cliff at the west end of the plateau and the approximately 18° inclined slope spreading below the cliff. This slope continues to the vicinity of the site of drill hole DHW-2 on the outlet side about 400 m from the underground powerhouse which is located at a depth about 350 m below it. From aerophotographs are interpreted lineaments running from south to north and from northwest to southeast.

The ground surface from the vicinity of the site DHW-2 to the outlet forms a mild slope with an inclination of about 8°. This slope is composed of colluvial deposit and talus deposit and a number of small irregular ups and downs can be seen on this slope. About 250 m to the south of the route of the outlet there is a shallow valley formed parallel to the route of the waterway. The topography of the bottom of the Lam Ta Khong reservoir around the outlet site presents a very gentle slope with an inclination smaller than 3°.

The Lam Ta Khong reservoir which will become a lower reservoir has a total length of 14 km and a width of about 2.5 km near the outlet site. The tailrace tunnel passes a depth of about 60 m below a highway (National Highway No.2) at a distance of about 250 m from the outlet.

7.6.2 Geology

There are very few outcrops near the waterway route and only coarse-grained sandstone is observed in the cliff at the west margin of the plateau and at the outcrop in the slope over the underground powerhouse. The geology of the waterway route that has been revealed on the basis of the results of drilling is shown in DWG. 7-4. The bedrock of this route consists of the Phu Kradung formation's siltstone, fine-grained sandstone and locally distributed conglomerate and the Phra Wihan formation's coarse-grained sandstone, claystone, siltstone and alternation of fine-grained sandstone and siltstone. Colluvial and talus deposit cover these bedrocks.

(1) Bedrock

The bedrock is classified as follows from bottom to top:

(a) Part consisting of siltstone layers and fine-grained sandstone layers (overall thickness: about more than 130 m)

(b) Siltstone layer with a thickness of about 180 m

(c) Alternation of fine-grained sandstone and siltstone with a thickness of about 180 m

(d) Claystone layer with a thickness of about 1 to 3 m

(e) Coarse-grained sandstone layer with a thickness of about 40 m

The siltstone in (a) has a reddish-purple to greenish gray color and a little low degree of consolidation and partly contains sandy siltstone with a relatively high degree of consolidation. The fine-grained sandstone in (a) is mainly massive, hard quartzose and of grayish-white color. It is confirmed that there are three layers of siltstone with a thickness of 20 to 35 m and three layers of fine-grained sandstone with a thickness of 3 to 20 m. Some parts consist of a alternation of fine-grained sandstone and siltstone with a unit bed thickness of several tens of centimeters.

Although the siltstone layer in (b) partly contains sandy siltstone with a relatively high degree of consolidation, most part consists of siltstone with a little low degree of consolidation varying in color from reddish-purple to greenish-gray.

The alternation of fine-grained sandstone and siltstone in (c) shows irregular alternation with a thickness of several tens of centimeters to 10 m consisting of medium-to-fine-grained quartzose sandstone of grayish-white color and siltstone varying in color from reddish-purple to greenish gray. Rocks of intermediate character is also intercalated such as silty sandstone and sandy siltstone. As for hardness of rock, the fine-grained sandstone is massive and hard while siltstone has a little low degree of consolidation and is a little soft. In (c) are contained two layers of coarse-grained sandstone with a thickness of about 10 m and 20 m respectively. This coarse-grained sandstone is mainly hard quartzose medium-grained sandstone with a little smaller grain size than that found in the upper reservoir site and a lamination developed in most parts and without a patch of claystone. The considerable part of siltstone in (a), (b) and (c) shows remarkable slaking.

(d) and (e) are the same as those mentioned in the section of the geology of the upper reservoir. The layers (a) to (c) are generally calcarious and micaceous, while the upper layers including those at the upper reservoir site above the layer (d) are noncalcarious.

Although the strike and dip of beds have not been directly measured, it is thought to be nearly the same as those at the upper reservoir site.

(2) Fault and Joint

During the reconnaissance no fault was found at all even at the places where the lineaments pass. The drilling resulted in a small fault shear zone being observed in the alternation of fine-grained sandstone and siltstone. The number of faults is summarized in Fig. 7-3 from the viewpoint of shear width and dip angle. The detailed fault data are attached in Appendix-A. The dip angles of the observed faults are mainly between 15° and 45°. The number of the fault with the shear zone of width more than 1 m totals up to 9 including 2 faults of unknown dip angle. The location of shear zones in drill cores is shown in DWG. 7-4. The fault at the depth of 70 m in DHU-1 is most remarkable and its dip is not clear and the apparent width of its shear zone which is mainly composed of rock fragments is 4.4 m.

Continuity of layers has been confirmed in the sections other than that between the sites of drilling DHW-1 and DHW-2 around the underground powerhouse. In view also of the fact that there are only a few faults in the peripheral region, it is thought that there is little possibility of a fault with large displacement existing in the waterway route.

The average joint frequency in each layer is shown in Fig. 7-1 in the same way as the joints of the upper reservoir site. The feature of the joints in alternation of fine-grained sandstone and siltstone, coarse-grained sandstone, siltstone, fine-grained sandstone which compose the bedrock of the waterway route is summarized as follows:

- The joints observed in outcrops and drill cores are divided into the following three types which are the same as those in the upper reservoir site:

  (a) Very low-angle joint with a dip of 5 ～ 15° (close to the dip of the bedding plane)

  (b) Low to medium-angle joint with a dip of 15 ～ 60°

(c) High-angle joint with a dip of 60 ~ 90°
Siltstone is rich in b-type joints and Sandstone in c-type joints.

- In alternation of sandstone and siltstone, especially siltstone part is rich in b-type joints of dip angle about 15° ~ 45°. The total frequency of this type of joints is about 8 joints/10 m.

- The most part of the joints in coarse-grained sandstone is c-type joint. The total frequency of the joints of this type is about 13 joints/10 m.

- Siltstone is rich in b-type joints of dip angle about 15° ~ 45°. Although the distribution of joints in siltstone is considerably inhomogeneous, the total frequency of this type of joints is about 16 joints/10 m averagely.

- Siltstone is rich in c-type joints. The total frequency of this type of joints is about 17 joints/10 m.

- Calcite veins (thickness: less than several mm) are often found in the beds at and below the alternation of fine-grained sandstone and siltstone. Gypsam veins (thickness: mainly less than several mm, maximum 2 cm) are distributed in the beds at and below the layer of siltstone at the lower part of penstock tunnel.

(3) Weathering

Influence of weathering is observed to a depth of about 70 m under the plateau as mentioned before, to a depth of 30 to 50 m under the slope between the penstock and the outlet and to a depth of about 20 m near the outlet. Consequently the waterway is located mostly in the unweathered bedrock while the intake, outlet and outlet gate only are located in the weathered bedrock.

In the middle and upper parts of the layer of coarse-grained sandstone at the intake, weathering is observed along the surface of joint only, but in the lowest part of 5 m thickness the whole bedrock is highly weathered and is softened because there is a ground water table in the neighborhood.

Colluvial and talus deposit are distributed in the ground surface in the area from the outlet gate to the outlet. In the bedrock below them there is no highly weathered part such as is seen in the upper reservoir site, weathering being observed along joints to a depth of 20 to 40 m. Particularly in this area the siltstone is remarkably softened due to the weathering.

(4) Surface Deposit

From the interpretation of aerophtographs and from the field reconnaissance it was assumed that thick colluvial and talus deposit was distributed in the slope from the underground powerhouse to the outlet. This distribution was confirmed by drilling. The deposit is thickest near the point of drilling DHT-1 and the maximum thickness is about 30 m. The deposit consists of rock fragments (maximum diameter about 5 m) of fine-to-coarse-grained sandstone and silt to clay material that fills them up. The rock fragments are derived from the sandstone that constitutes the bedrock and are in different degrees of weathering. The deposit including sandstone fragments is widely distributed in the lower part of the slope where no sandstone is distributed in the bedrock, this means that the sandstone fragments were transported for more than 1 km in horizontal distance. In this deposit large blocks with a diameter of a few meters composed of the siltstone that constitutes the bedrock are contained. It is assumed from these features that the deposit was formed by passed landslide.

No sedimentary structure is found in this deposit. The boundary with the bedrock is transitional and unclear in many parts. The DHT-1 drill core showed slickensides with a dip of 5 to 15° in the deposit near the border with the bedrock and therefore there may be a slip surface formed in the deposit. This kind of slip surface was found only at this point. Judging from the geological and topographical conditions of the surrounding area it is not considered as a large active landslide surface, however it requires attention to be paid in the future investigation because it may become unstable by excavation of the slope.

(5) Ground Water Level

The water levels in the drill holes at the waterway route are shown in DWG. 7-4 and Fig. 7-2. As described before, the ground water level at the upper reservoir site is located in the lower part of coarse-grained sandstone layer of the bedrock at the upper reservoir dam. It has not been lowered even at the point of drilling DHW-1 near the west end of the plateau. In the slope way down from the penstock, the ground water level is located at a depth of 20 to 40 m below the ground surface or a few meters depth from the surface of the bedrock.

Surface water around the waterway route was found just under the outcrop of coarse-grained sandstone in (c) layer mentioned before and in a valley about 250 m to the south of the waterway route. It was not immediately after a rainfall the surface water in the valley was found running from a point having an elevation of 320 m to the Lam Ta Khong reservoir. In the valley no bedrock is exposed and although permeable surface deposit is distributed, there is water in the valley. From this fact, it is thought to be highly possible that the bedrock is distributed under the slopes on the both banks of the valley and that the ground water level in the banks is higher than the bottom of the valley.

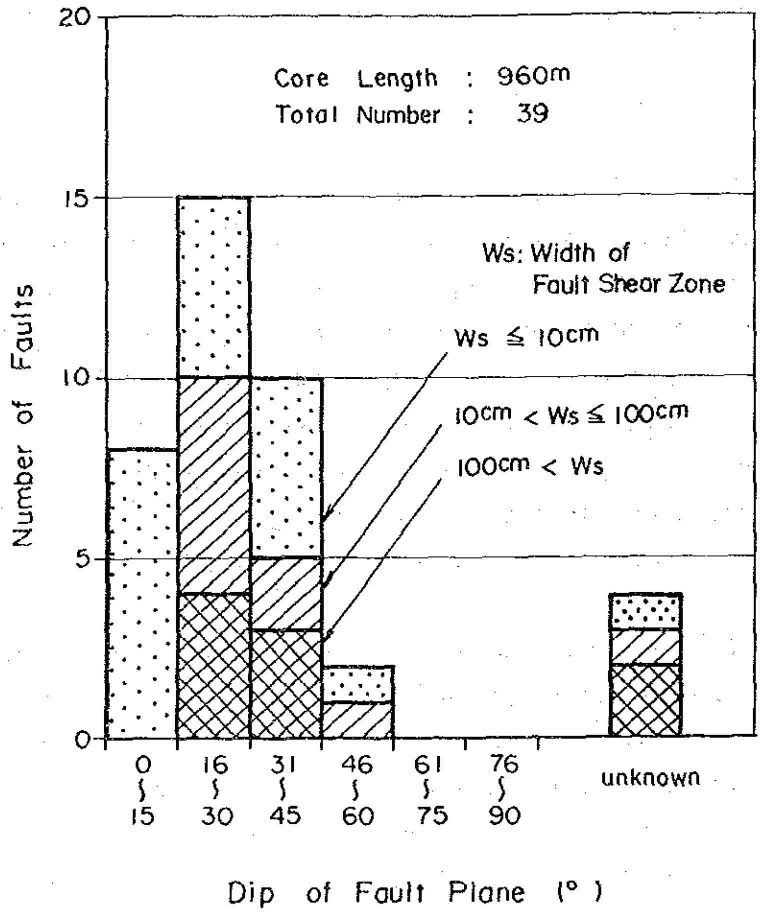


Fig. 7-3 Fault Number in Drill Cores

7.7 Seismic Prospecting in Upper Reservoir Site

Seismic prospecting (refraction method) was carried out for the purpose of grasping the geologic conditions of the upper reservoir site.

(1) Location and Quantity

The quantity of seismic prospecting is four lines of 900 m length and totals to 3,600 m. The layout of the lines is shown in DWG. 7-2.

(2) Method

The measurement was performed by the signal enhancement of shock waves mainly from multiple hammer blows with the geophone interval 5 to 10 m and the hit point interval 50 m. The apparatus used in the measurement are listed below.

(a) Seismograph

Name	ES-1210	McSEIS 1300 MODEL-1191
Maker	GeoMetrics/nimbus (USA)	OYO (Japan)
Channel No.	12	12
Maximum gain	96	86
Frequency Response	3 - 800 Hz	5 - 1000 Hz
Sampling Rate	2048 - 51.2 samples/ms	20 - 1 samples/ms
Record Length	51.2 - 2048 ms	50 - 1000 ms

(b) Geophone

OYO (USA) : frequency 28 Hz

(3) Results

The data were analyzed by Hagiwara's method and its expanded version. The time-distance curves and seismic profiles obtained by the analysis are shown in DWG. 7-6. Since blasting could not have been used, many received wave forms by far shots were not clear. These data were distinguished as unreliable data as shown in the drawings and were not used for the analysis.

The results, which are summarized in Table 7-7, are nearly concordant with that of the investigation by the drilling. The 1st layer of 1 to 5 m in thickness corresponds to residual soil and the 2nd layer of 2 to 10 m in thickness corresponds to weathered claystone or highly weathered coarse-grained sandstone.

Table 7-7 Summary of Seismic Prospecting

Layer No.	P-wave Velocity (km/s)	Thickness (m)	Geologic Condition	Ripperbility
1st layer	0.3~0.5	1 ~ 5	・residual soil	ripperble
2nd layer	0.6~0.8 0.8~1.0	2 ~ 10	・weathered claystone ・highly weathered coarse-grained sandstone	ripperble
3rd layer	2.0~2.2 2.2~2.4	6 ~ 15	・claystone ・moderately weathered coarse-grained sandstone ・coarse-grained sandstone including claystone patch	ripperble not ripperble
4th layer	4.0~4.2 4.2~4.4	——	・slightly weathered coarse-grained sandstone	not ripperble

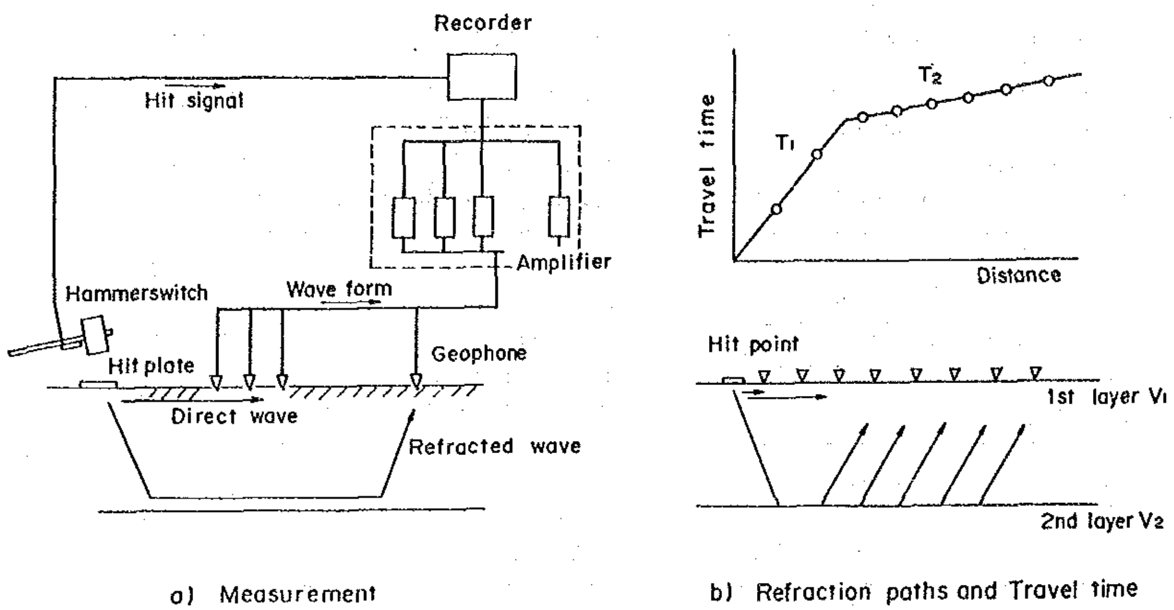
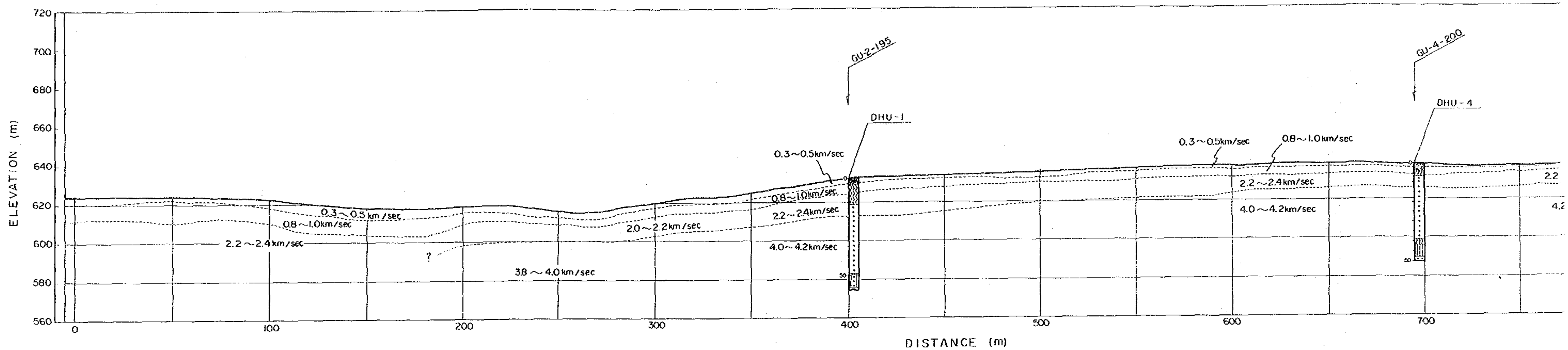
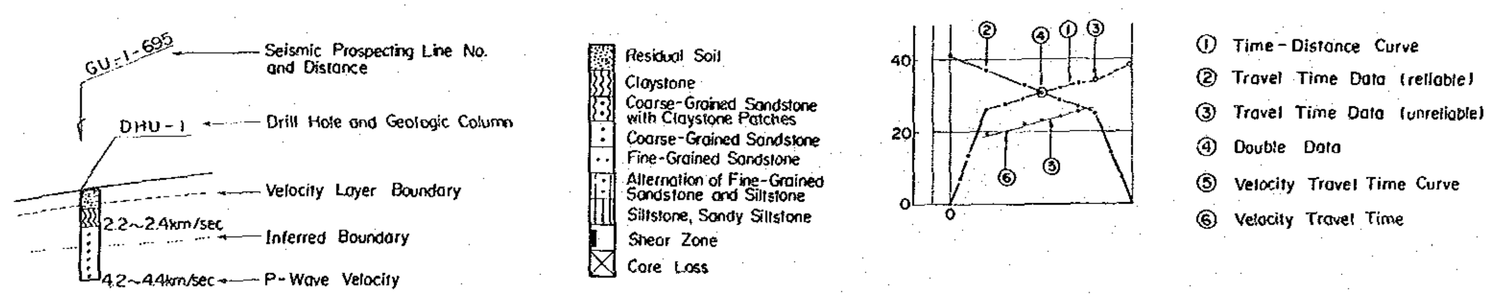


Fig. 7-4 Diagram of Seismic Prospecting Method

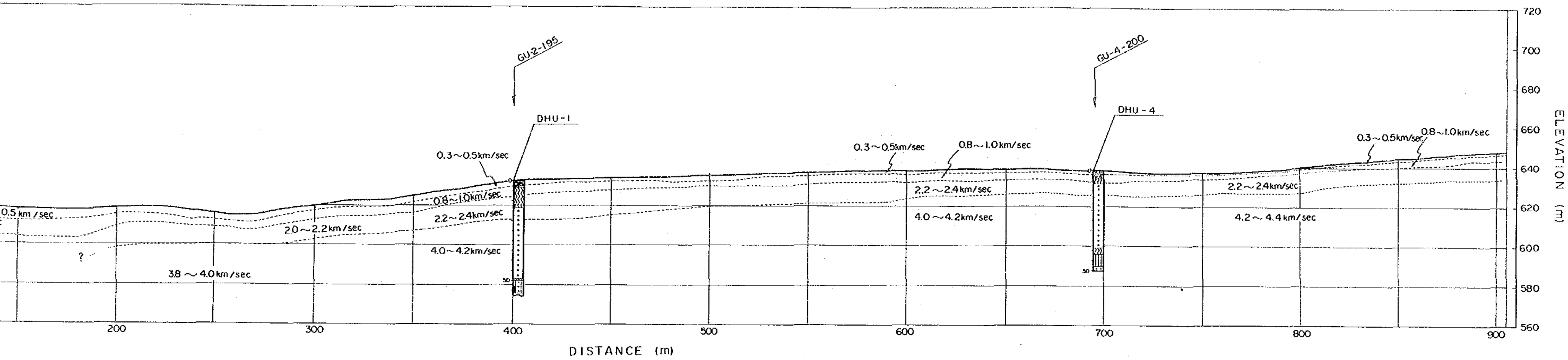


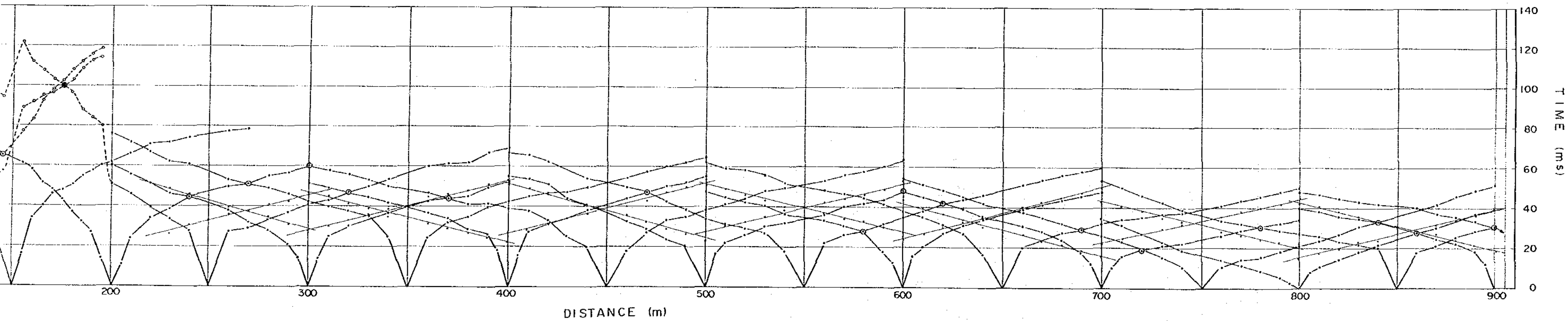
GU-2-195
GU-4-200
DHU-1
DHU-4
ELEVATION (m)
0.3～0.5km/sec
0.8～1.0km/sec
2.2～2.4km/sec
2.0～2.2km/sec
3.8～4.0km/sec
4.0～4.2km/sec
DISTANCE (m)
TIME (ms)
DISTANCE (m)

LEGEND

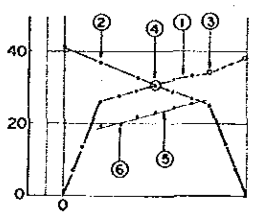


GU-1-695
Seismic Prospecting Line No. and Distance
DHU-1
Drill Hole and Geologic Column
Velocity Layer Boundary
2.2～2.4km/sec
Inferred Boundary
4.2～4.4km/sec
P-Wave Velocity
Residual Soil
Claystone
Coarse-Grained Sandstone with Claystone Patches
Coarse-Grained Sandstone
Fine-Grained Sandstone
Alternation of Fine-Grained Sandstone and Siltstone
Siltstone, Sandy Siltstone
Shear Zone
Core Loss
① Time-Distance Curve
② Travel Time Data (reliable)
③ Travel Time Data (unreliable)
④ Double Data
⑤ Velocity Travel Time Curve
⑥ Velocity Travel Time





Residual Soil
Claystone
Coarse-Grained Sandstone with Claystone Patches
Coarse-Grained Sandstone
Fine-Grained Sandstone
Alternation of Fine-Grained Sandstone and Siltstone
Siltstone, Sandy Siltstone
Shear Zone
Core Loss



① Time-Distance Curve
② Travel Time Data (reliable)
③ Travel Time Data (unreliable)
④ Double Data
⑤ Velocity Travel Time Curve
⑥ Velocity Travel Time

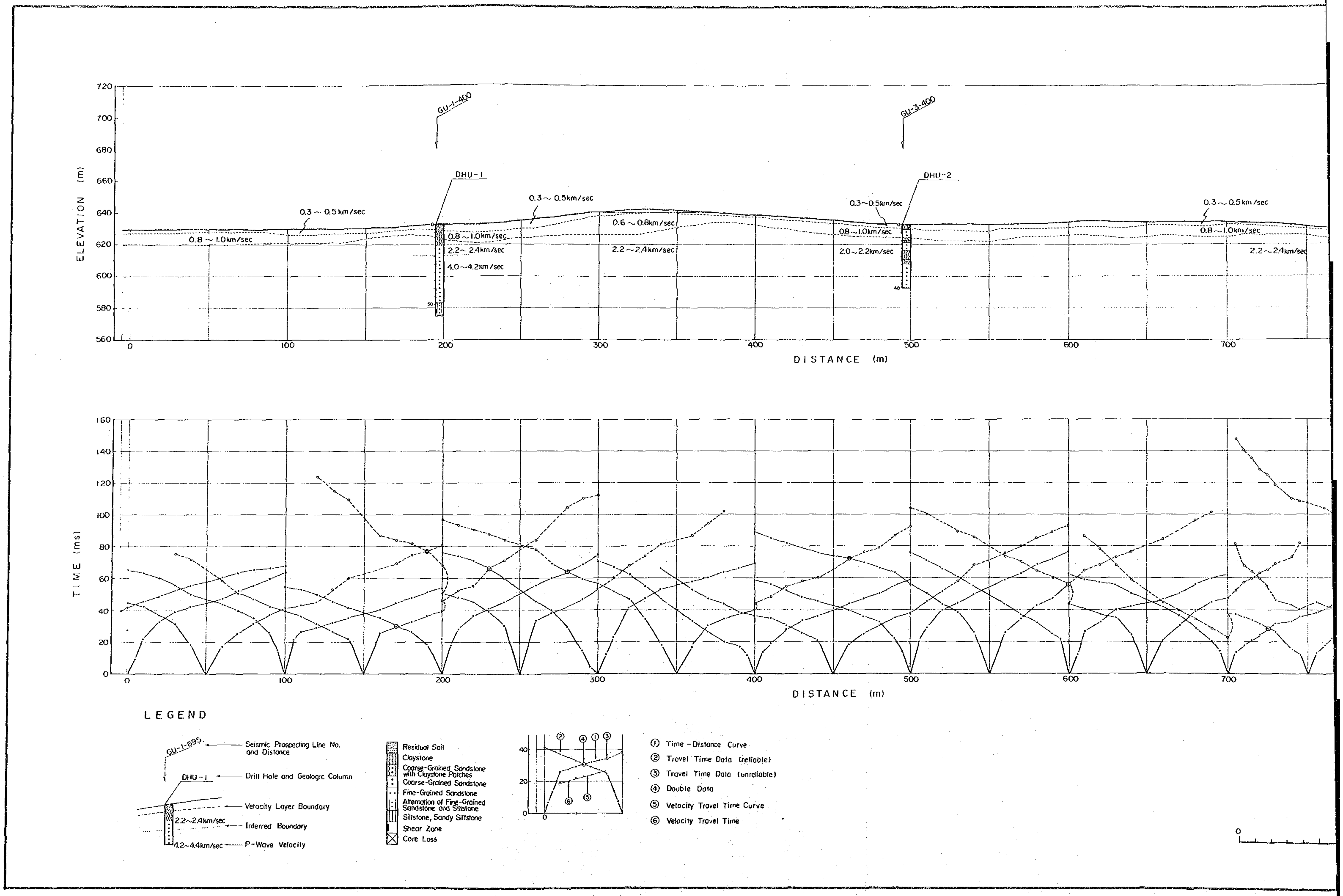
0 100m

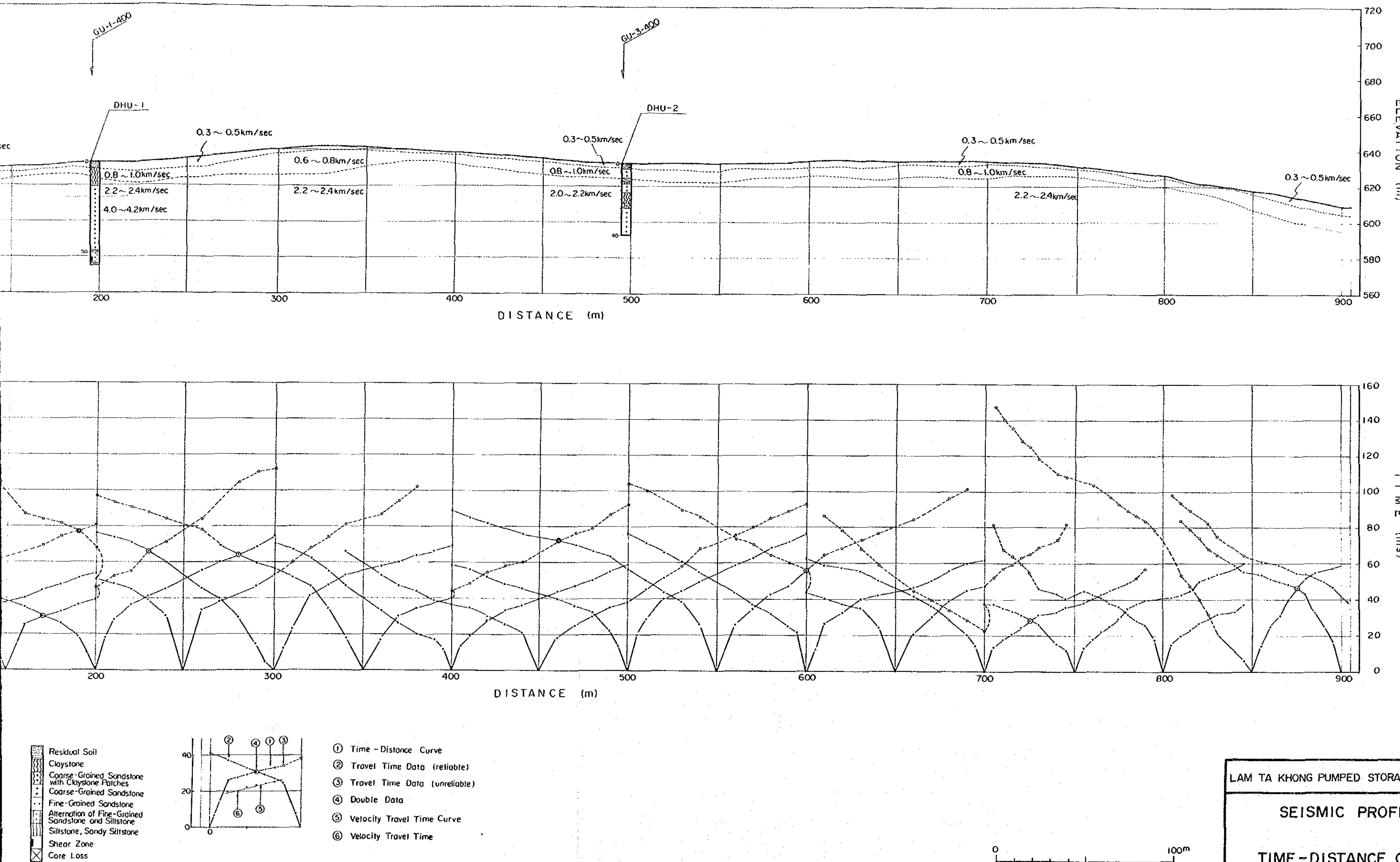
LAM TA KHONG PUMPED STORAGE PROJECT

SEISMIC PROFILE

TIME-DISTANCE CURVE (GU-1)

DWG. 7-6 (1)


GU-1-400
GU-3-400
DHU-1
DHU-2
ELEVATION (m)
0.3 ~ 0.5 km/sec
0.8 ~ 1.0km/sec
0.3 ~ 0.5km/sec
0.6 ~ 0.8km/sec
0.8 ~ 1.0km/sec
2.2 ~ 2.4km/sec
4.0 ~ 4.2km/sec
2.2 ~ 2.4km/sec
0.3~0.5km/sec
0.8~1.0km/sec
2.0~2.2km/sec
0.3 ~ 0.5km/sec
0.8 ~ 1.0km/sec
2.2 ~ 2.4km/sec
DISTANCE (m)
TIME (ms)
DISTANCE (m)
LEGEND
GU-1-695
Seismic Prospecting Line No. and Distance
DHU-1
Drill Hole and Geologic Column
Velocity Layer Boundary
2.2~2.4km/sec
Inferred Boundary
4.2~4.4km/sec
P-Wave Velocity
Residual Soil
Claystone
Coarse-Grained Sandstone with Claystone Patches
Coarse-Grained Sandstone
Fine-Grained Sandstone
Alternation of Fine-Grained Sandstone and Siltstone
Siltstone, Sandy Siltstone
Shear Zone
Core Loss
① Time - Distance Curve
② Travel Time Data (reliable)
③ Travel Time Data (unreliable)
④ Double Data
⑤ Velocity Travel Time Curve
⑥ Velocity Travel Time

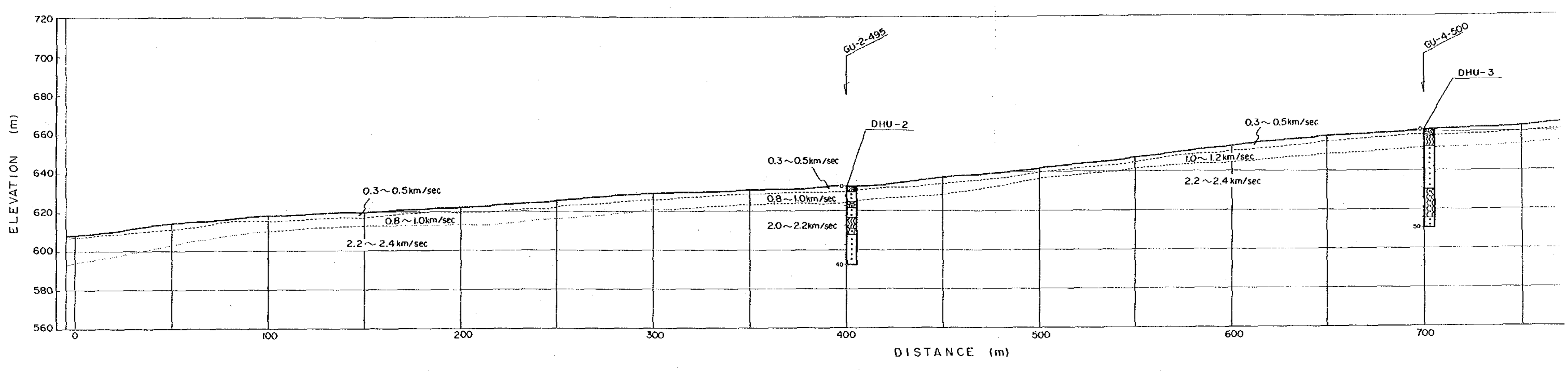


LAM TA KHONG PUMPED STORAGE PROJECT

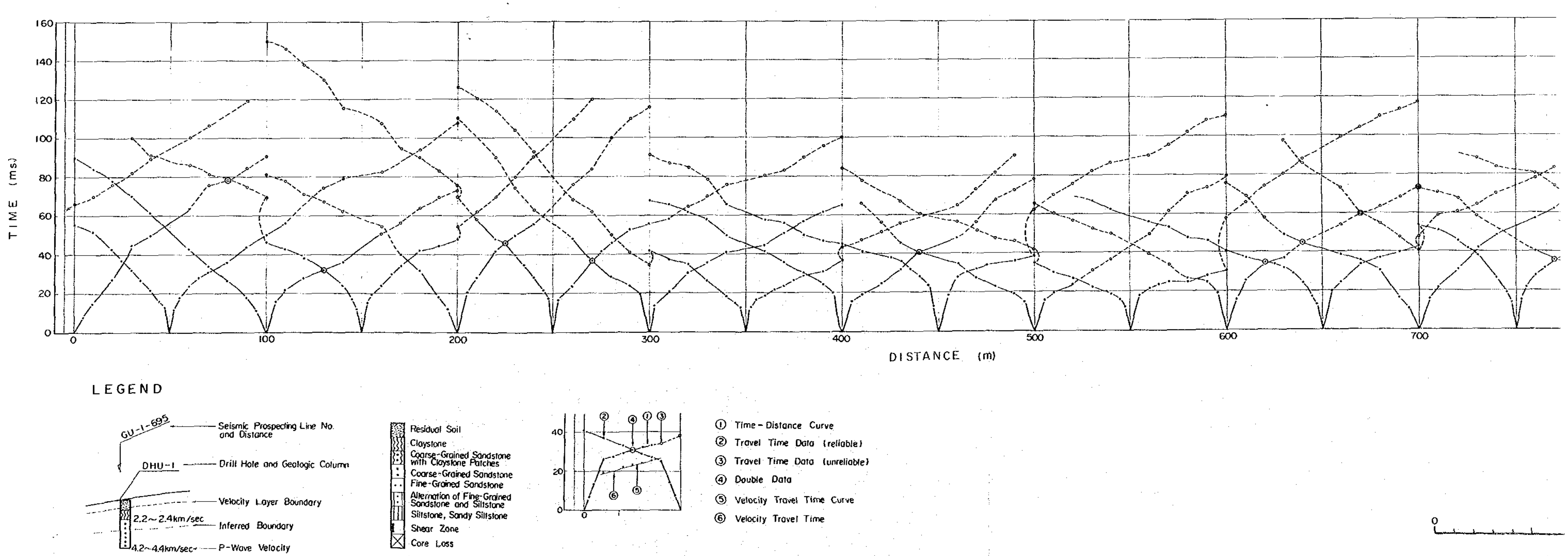
SEISMIC PROFILE

TIME-DISTANCE CURVE
(GU-2)

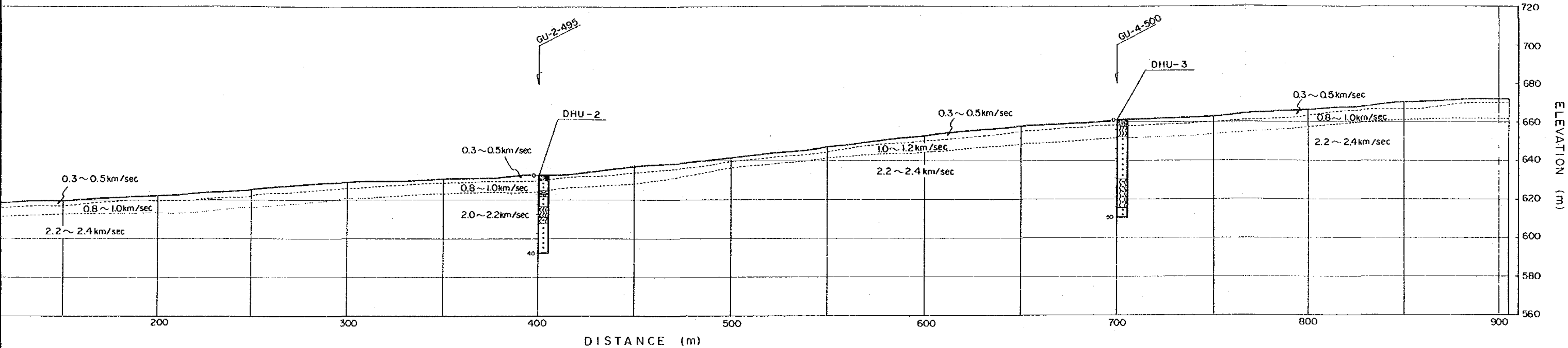
DWG. 7-6 (2)

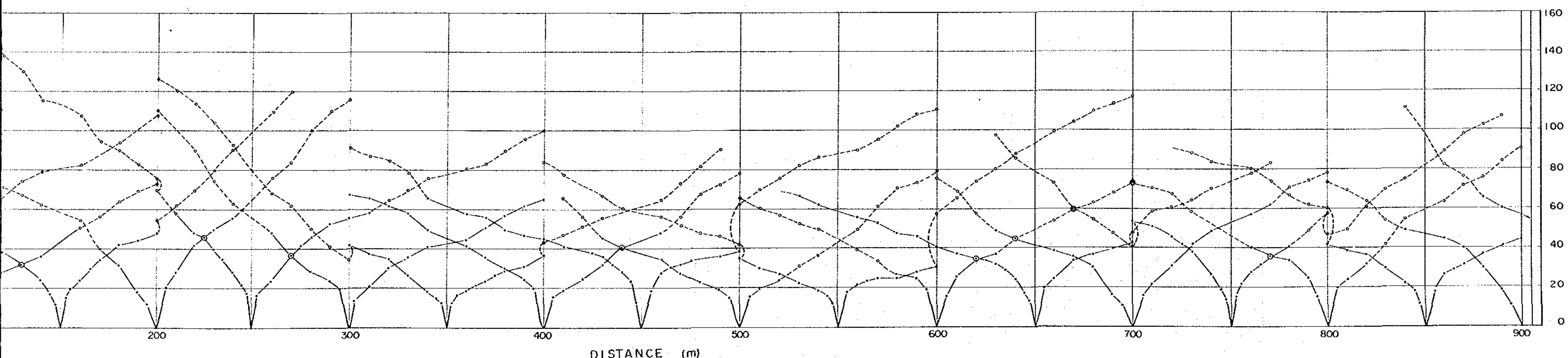


ELEVATION (m)
720
700
680
660
640
620
600
580
560
GU-2-495
GU-4-500
DHU-2
DHU-3
0.3～0.5km/sec
0.8～1.0km/sec
2.2～2.4km/sec
2.0～2.2km/sec
1.0～1.2km/sec
0
100
200
300
400
500
600
700
DISTANCE (m)
TIME (ms)
160
140
120
100
80
60
40
20
DISTANCE (m)



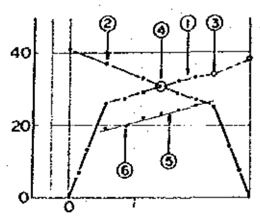
LEGEND
GU-1-695
Seismic Prospecting Line No. and Distance
DHU-1
Drill Hole and Geologic Column
Velocity Layer Boundary
2.2～2.4km/sec
Inferred Boundary
4.2～4.4km/sec
P-Wave Velocity
Residual Soil
Claystone
Coarse-Grained Sandstone with Claystone Patches
Coarse-Grained Sandstone
Fine-Grained Sandstone
Alternation of Fine-Grained Sandstone and Siltstone
Siltstone, Sandy Siltstone
Shear Zone
Core Loss
① Time-Distance Curve
② Travel Time Data (reliable)
③ Travel Time Data (unreliable)
④ Double Data
⑤ Velocity Travel Time Curve
⑥ Velocity Travel Time





Line No.
Geologic Column
Boundary

- Residual Soil
- Claystone
- Coarse-Grained Sandstone with Claystone Patches
- Coarse-Grained Sandstone
- Fine-Grained Sandstone
- Alternation of Fine-Grained Sandstone and Siltstone
- Siltstone, Sandy Siltstone
- Shear Zone
- Core Loss



① Time - Distance Curve
② Travel Time Data (reliable)
③ Travel Time Data (unreliable)
④ Double Data
⑤ Velocity Travel Time Curve
⑥ Velocity Travel Time

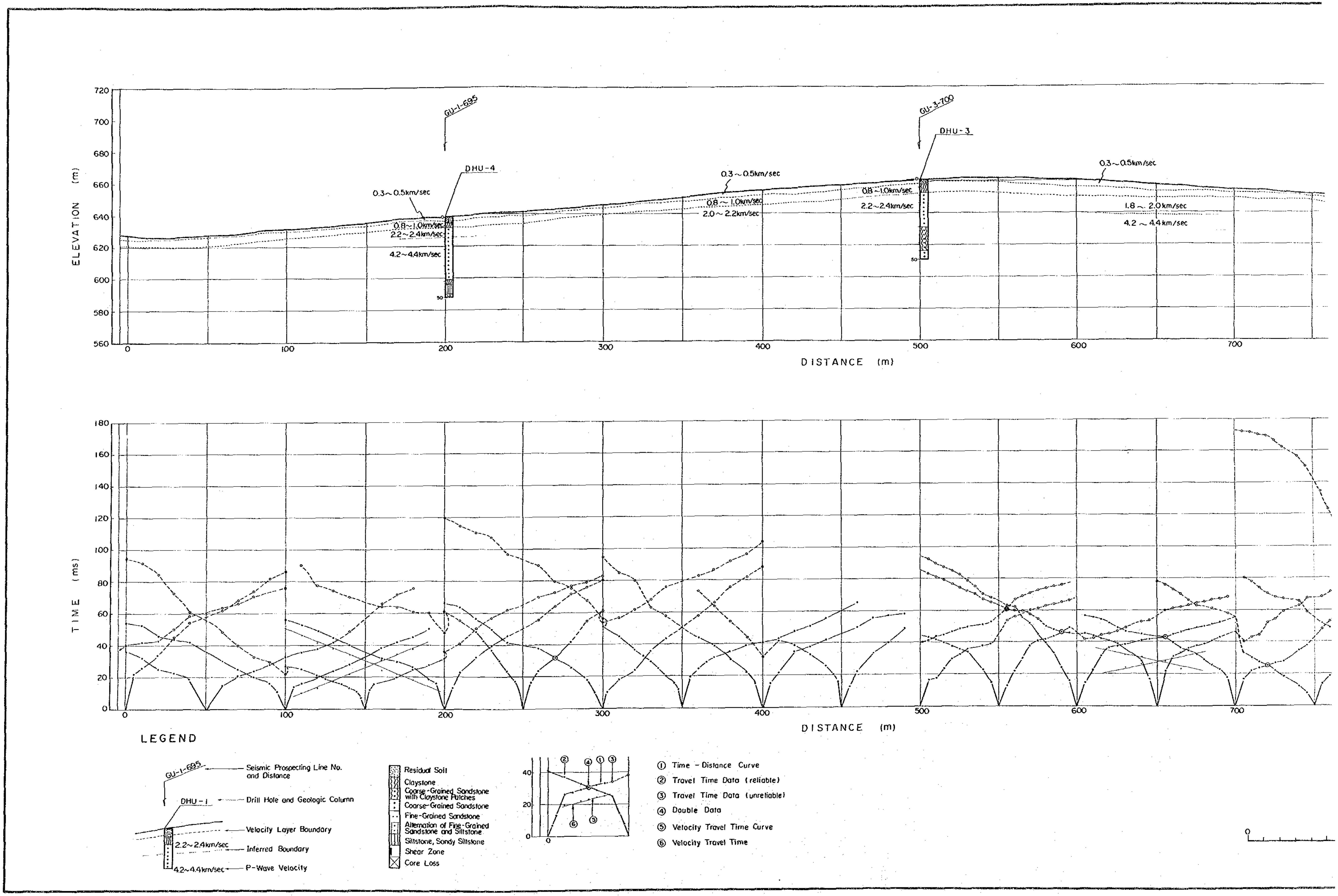
0 100m

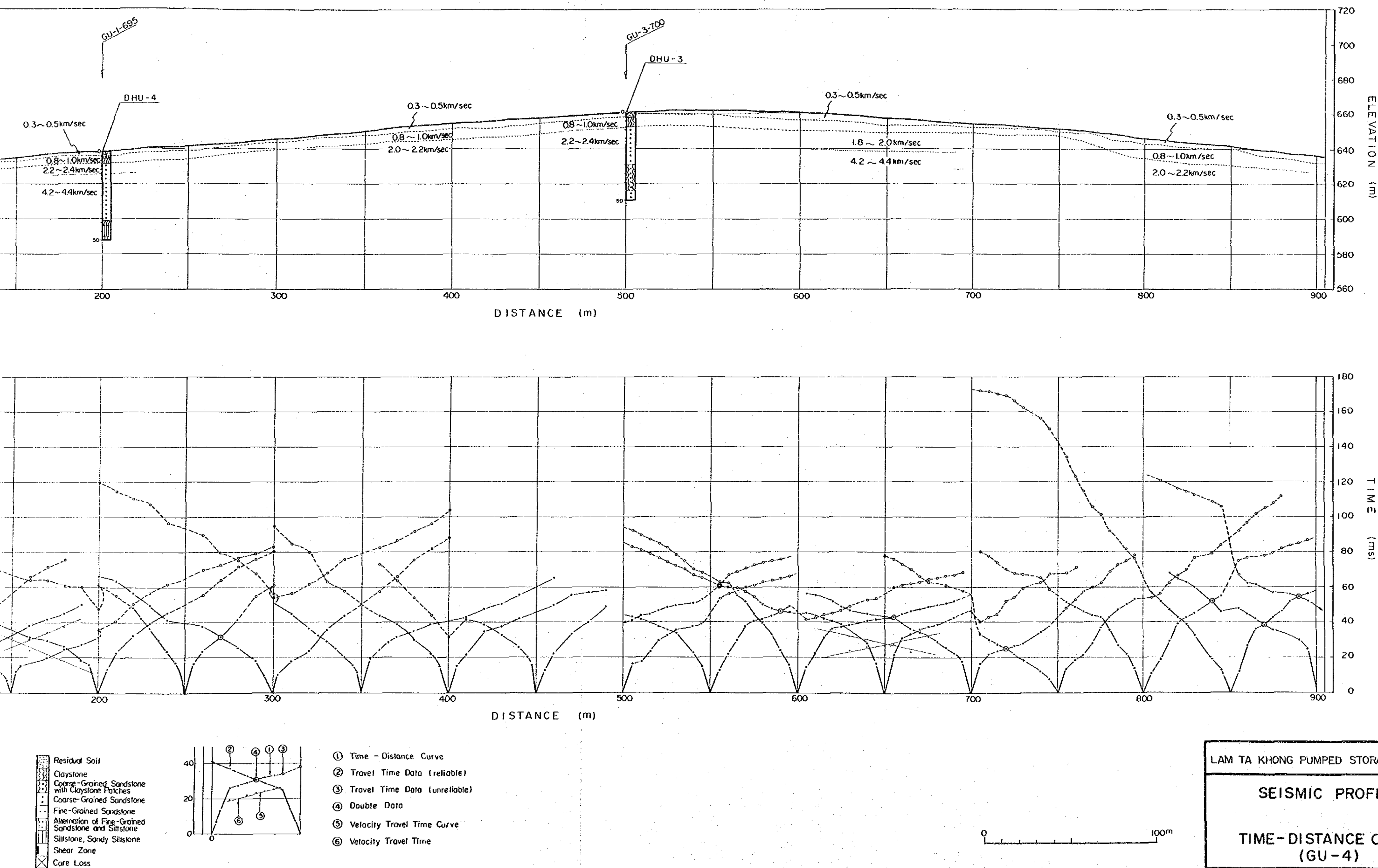
LAM TA KHONG PUMPED STORAGE PROJECT

SEISMIC PROFILE

TIME - DISTANCE CURVE (GU-3)

DWG. 7-6 (3)


GU-1-695
GU-3-700
DHU-4
DHU-3
0.3～0.5km/sec
0.8～1.0km/sec
2.2～2.4km/sec
4.2～4.4km/sec
2.0～2.2km/sec
1.8～2.0km/sec
ELEVATION (m)
DISTANCE (m)
TIME (ms)
LEGEND
Seismic Prospecting Line No. and Distance
Drill Hole and Geologic Column
Velocity Layer Boundary
Inferred Boundary
P-Wave Velocity
Residual Soil
Claystone
Coarse-Grained Sandstone with Claystone Patches
Coarse-Grained Sandstone
Fine-Grained Sandstone
Alternation of Fine-Grained Sandstone and Siltstone
Siltstone, Sandy Siltstone
Shear Zone
Core Loss
① Time - Distance Curve
② Travel Time Data (reliable)
③ Travel Time Data (unreliable)
④ Double Data
⑤ Velocity Travel Time Curve
⑥ Velocity Travel Time



LAM TA KHONG PUMPED STORAGE PROJECT

SEISMIC PROFILE

TIME-DISTANCE CURVE (GU-4)

DWG. 7-6 (4)

7.8 Standard Penetration Test

The location and the quantity of the test are shown in Table 7-2.

The results of the test are shown in Table 7-8. The test results of DHU-1 ~ 5 and DHW-1 in the upper reservoir site show that the N-values of residual soil and the highly weathered rock near the surface of bedrock are under 50 while the N-values of the depth about 5 m are above 50. The part remarkably softened by weathering is thin.

The tests in drill holes of the waterway route were carried out in colluvial and talus deposit. Large N-values were measured in these tests presumably because of the influence of rock fragments.

Table 7-8 Results of Standard Penetration Test

Drill Hole	Depth (m)	N-value	Description		
			Geology (Rock Classification)	Water Cont.	Plasticity
DHU-1	1.15 ~ 1.45	8	Residual soil : clayey silt	moist	low
	2.15 ~ 2.45	8			
	3.15 ~ 3.45	21	Weathered claystone (4-5, 5, 4-5)*	moist	low
	4.15 ~ 4.45	36			
	5.15 ~ 5.45	52			
DHU-2	1.15 ~ 1.45	29	Residual soil : silt with gravel	moist	low
	2.15 ~ 2.45	80			
DHU-3	1.15 ~ 1.45	70	Residual soil : silt	moist	low
	2.15 ~ 2.45	67			
	4.70 ~ 5.00	30/1.5"	Weathered claystone (4-5, 4-5, 4-5)*	moist	low
DHU-4	1.15 ~ 1.45	43	Residual soil : clayey silt.	moist	low
	2.15 ~ 2.45	40	Residual soil : silt with gravel	moist	low
	3.15 ~ 3.45	35			
	4.15 ~ 4.45	64	Weathered claystone (5, 4, 4)*	moist	low
DHU-5	1.15 ~ 1.45	60/4.5"	Weathered coarse-grained sandstone	moist	very low
DHW-1	3.15 ~ 3.45	42	Weathered claystone (4-5, 4-5, 4)*	moist	low
	4.15 ~ 4.45	70			
DHW-2	1.00 ~ 1.45	5	Residual soil : clayey silt	moist	medium
	2.00 ~ 2.45	10		moist	low
	3.00 ~ 3.45	17			
	4.40 ~ 4.50	70/4"	Residual soil : silt with gravel	moist	low
DHT-2	1.15 ~ 1.45	9	Residual soil : silt with gravel	moist	very low
	2.15 ~ 2.45	43			

* (weathering, hardness, crack spacing) , see Table 7-19

7.9 Permeability Test

7.9.1 Permeability Test in Drill Holes

Lugeon test was carried out in drill holes. In the section where it was impossible to get high pressure due to high permeability, constant head permeability test was carried out. If a critical pressure was found in test data, converted lugeon value was calculated from discharge value under the critical pressure. (see Table 7-9)

For the test data showing large discharge, friction pressure loss in rods were evaluated in the calculation of lugeon value (Table 7-10). Friction pressure loss in the rods of 20 mm in diameter (*) was calculated on the basis of the test results (Fig. 7-5) carried out by EGAT. For the wire-line drilling rods of 60.3 mm in diameter of DHW-1, DHW-2 and DHT-1, it is concluded that the influence of friction pressure loss is little on the basis of the Weisbach's equation (**).

* $Pl = 3.5 \times 10^{-5} Q^{1.84} L$ where Pl : Pressure loss ($kgf/cm^2/m$)

** $Pl = 8.6 \times 10^{-8} Q^2 L$ Q : Discharge (l/min)

L : Length of rod (m)

Tests results are shown in DWG. 7-4, DWG. 7-5 and Table 7-10. The detailed test data are attached in Appendix-A. As to rock types, there are many sections of high permeability in coarse to fine-grained sandstone, even if it is weathered or not. While the lugeon values of siltstone excluding sandy part and weathered one are mostly under 1 Lu, and it forms the bedrock of low permeability.

7.9.2 Permeability Test in Pits

The following two kinds of permeability tests were performed in the test pits in the upper reservoir site.

- Uncased well permeameter method: EARTH MANUAL (U.S. Department of the Interior) Field Permeability Test (Well Permeameter method), Designation E-19

- Open-end pipe method: EARTH MANUAL (U.S. Department of the Interior) Field Permeability Tests in Boreholes, Designation E-18

The test results are shown in Table 7-12. All results show that the permeability coefficient of highly weathered claystone is 1 ~ 2×10^{-5} cm/s. Geologic sketches of test pits and the detailed test data are attached in Appendix-A.

Table 7-9 Critical Pressure of Bedrock

Drill Hole Number	Test Depth (m)	Geology	Critical Pressure (kgf/cm²)
DHU-2	5.0-10.0	Coarse-grained sandstone and claystone	1.6
DHU-5	5.0-10.0	Coarse-grained sandstone	1.2
DHW-1	75.0-81.0	Siltstone	9.7
DHW-1	117.5-23.5	Siltstone and alternation of fine-grained sandstone and siltstone	9.3
DHW-2	27.5-33.5	Siltstone	3.9
DHT-1	21.0-25.0	Talus deposit	4.3
DHT-2	20.0-25.0	Alternation of fine-grained sandstone and siltstone	5.8
DHT-2	35.0-40.0	Fine-grained sandstone and siltstone	6.7
DHT-3	5.0-10.0	Talus deposit and siltstone	1.6

Table 7-10 Lugeon Value and Friction Head Loss in Drill Hole

Drill Hole Number	Test Depth (m)	Geology	Apparent Effective Pressure (kgf/cm²)	Discharge (ℓ/min)	Apparent Lugeon Value (Lu)	Friction Pressure Loss (kgf/cm²)	Effective Pressure (kgf/cm²)	Lugeon Value (Lu)
DHU-1	15.0-20.0	Coarse-grained sandstone	2.97	46.0	30.9	0.6	2.4	38
DHU-1	40.0-45.0	Coarse-grained sandstone	3.3	53.4	32.4	0.8	2.5	43
DHU-2	25.0-30.0	Coarse-grained sandstone	6.1	21.8	7.1	0.3	5.8	7.5
DHU-3	45.0-50.0	Coarse-grained sandstone, claystone	2.9	77.0	53.1	4.7	0	100<
DHU-4	35.0-40.0	Coarse-grained sandstone, claystone	6.3	37.2	11.8	1.0	5.3	14
DHU-4	45.0-50.0	siltstone, Fine-grained sandstone	9.7	47.2	9.7	1.9	7.8	12

Table 7-11 Summary of Lugeon Test

Geology		Rock Classification and Rock Evaluation *		Data Qt.	Lugeon Value (Lu)	
Rock Name	Description	W, H, C	RE		Range	Mean
Colluvial deposit, Talus deposit		——	—	2	11~13	12
Coarse-grained sandstone	fresh part	1-2, 1-3, 1-3	H1	5	0.1~22<	5.2<
	weathered part	2-4, 1-4, 1-4	H1-H3	22	0.3~100<	10<
	with claystone	3-4, 2-4, 3-4	H3	3	0.8~1.7	1.2
Fine-grained sandstone	fresh part	1, 1-4, 1-3	H1-H3	10	0.4~29<	8.6<
	weathered part	2-3, 3-4, 2-4	H2-H3	3	0.1~2.2	1.4
Alternation of fine-grained sandstone and siltstone	fresh part	1-2, 2-4, 1-3	H1-H3	2	0.4~3.5	2.0
	weathered part	-4, 3-4, 3-5	H2-H3	1	0.3	0.3
Siltstone	fresh part	1-2, 3-4, 1-4	S2 (partly S1, S3)	54	0.0~8.5	0.7
	weathered part	3-4, 3-4, 2-5	S2-S3	3	0.4~19	7.0

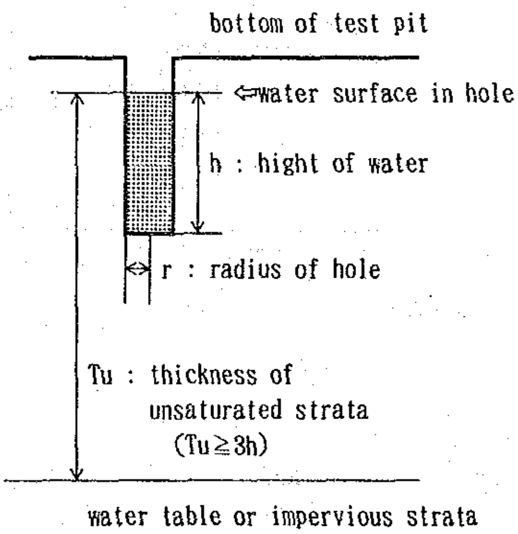
* see Table 7-19, 7-20 ; W : weathering H : hardness C : crack spacing
weathered part : 3 ≦ W

Table 7-12 Results of Permeability Tests in Test Pits

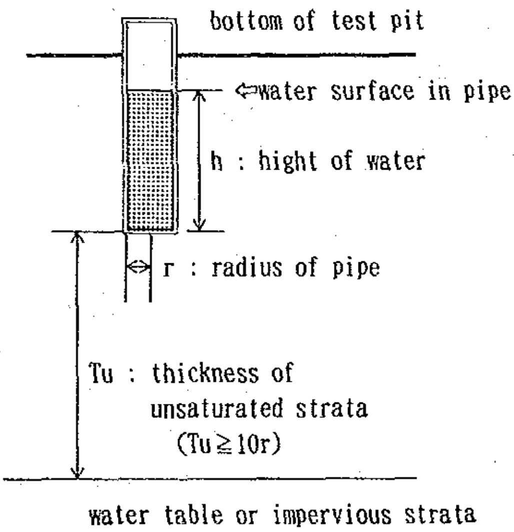
Test Pit	PU-1	PU-1	PU-3	PU-3
Test Method	Well permeameter #1	Open end pipe #2	Well permeameter	Open end pipe
Test Depth (m)	5.0-5.6	5.7	4.9-5.5	5.6
Geology	Weathered claystone (W:4-5, H:4-5, C:4-5, Rock Evaluation: S3) ※			
Test hole radius r (cm)	6.6	15.0	6.85	15.0
Hight of water h (cm)	68.0	24.4	64.0	23.7
Discharge rate Q (cm^3/s)	0.25	0.0393	0.113	0.0321
Permeability k (cm/s)	1.7×10^{-5} *1	2.0×10^{-5} *3	0.89×10^{-5} *2	1.6×10^{-5} *3

※ see Table 7-19, 7-20 ; W : weathering H : hardness C : crack spacing

#1: Well permeameter test



#2: Open end pipe test



*1 when $h \geqq 10r$,

$$k = \frac{Q}{2\pi h^2}\left[\ln\left\{\frac{h}{r} + \sqrt{1+\left(\frac{h}{r}\right)^2}\right\} - 1 \right]$$

*2 when $h < 10r$,

$$k = \frac{Q}{2\pi h^2}\left[\ln\left\{\frac{h}{r} + \sqrt{1+\left(\frac{h}{r}\right)^2}\right\} - \sqrt{1+\left(\frac{r}{h}\right)^2} + \frac{r}{h} \right]$$

*3 $k = \dfrac{Q}{5.5\, r\, h}$

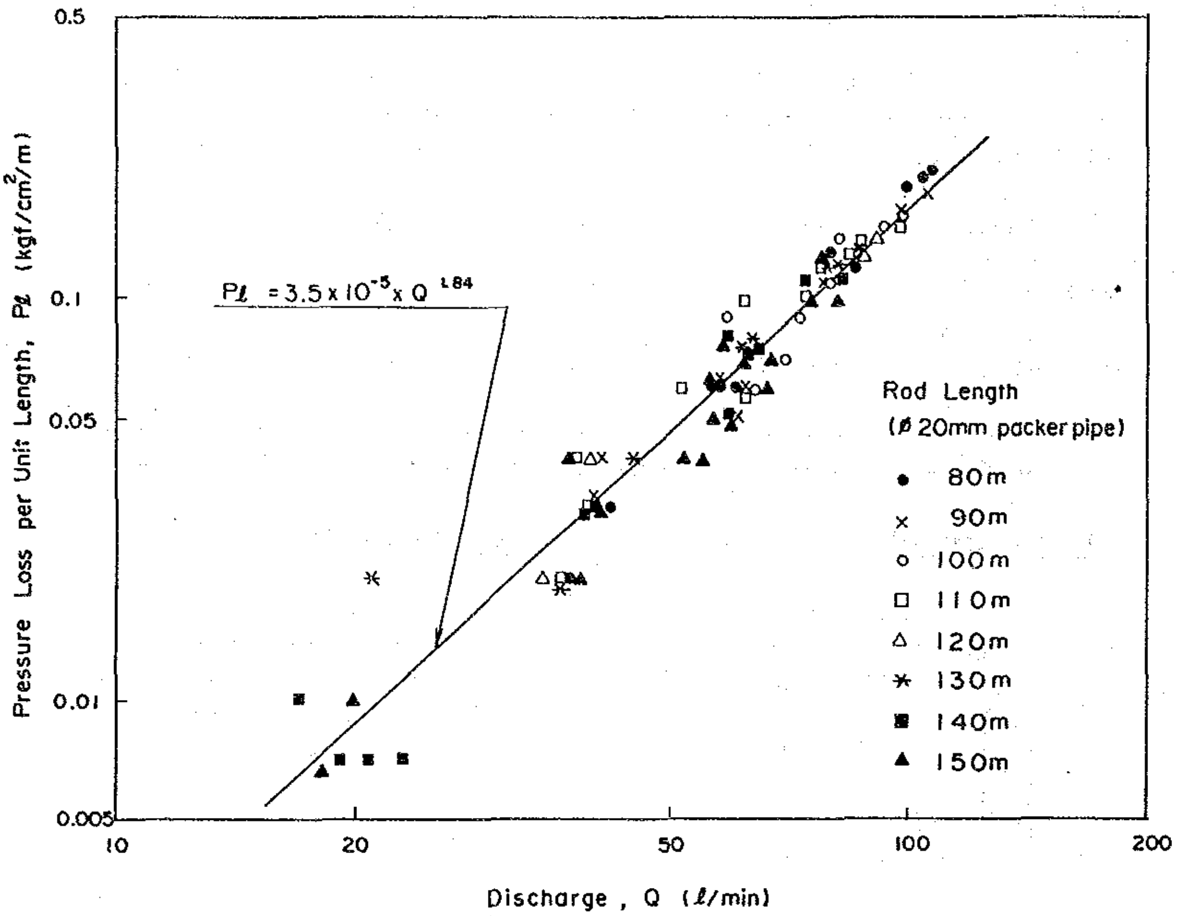


Fig. 7-5 Test Data for Friction Head Loss in Drill Rod

7.10 Drill Hole Deformation Test

Pressure-displacement relation was measured on the wall of drill hole using a cylindrical rubber tube that was expanded radially for the purpose of grasping the deformability of bedrock.

(1) Location and Quantity

The tests were performed at the representative bedrocks in the drill holes of upper reservoir (2 holes), waterway (2 holes) and tailrace (3 holes). The quantity of the test totals 41.

(2) Method

The outline of drill hole deformation test is shown in Fig. 7-6. The pressure and displacement were measured under cyclic loading condition by the use of the test apparatus, Elastmeter 200 (OYO, Japan). Specifications of Elastmeter 200 are as follows:

Name	:	Elastmeter 200 MODEL 4130
Maximum pressure	:	200 kgf/cm^2
Rubber tube length	:	520 mm
Displacement measuring system	:	Contact balancer method
Measurement of radial displacement	:	Measurement limit 9.5 m
	:	Minimum scale 0.01 mm,
Pressure unit	:	Water pressure pump

The standard loading pattern was as follows, however, peak pressures were changed to the adequate values in some cases according to the geologic conditions of bedrocks or the depth of the test points. Unloading from peak pressure was performed during about 1 minute.

Peak pressure	:	25, 50, 100, 100 kgf/cm^2
Loading rate	:	5 kgf/cm^2/min
Peak pressure holding time	:	4 minutes
Bottom pressure holding time	:	4 minutes

(3) Analysis

Deformation modulus and secant elastic modulus could be obtained from pressure-radial displacement relation by the following equation. Deformation modulus and secant elastic modulus were calculated from the radial displacement at the vergin loading and at the reloading respectively.

$$D \text{ or } Es = (1 + \nu) \cdot Rm \cdot \Delta P / \Delta r$$

where,	D	:	Deformation Modulus	(kgf/cm^2)
	Es	:	Secant Elastic Modulus	(kgf/cm^2)
	ν	:	Poisson's Ratio (assumed to be 0.3)	
	Rm	:	Mean Drill Hole Radius	(cm)
	ΔP	:	Pressure increment	(kgf/cm^2)
	Δr	:	Radial displacement increment	(cm)

Yield pressure could be obtained from the point where the pressure-displacement curve deviates from straight line.

(4) Results

The test results are listed in Table 7-13. The detailed test data are attached in Appendix-A. In DHW-2 which is the nearest drill hole to the underground powerhouse site, reliable results could not be obtained because of the incomplete adjustment of the test apparatus, although 6 test points had been planned in the drill hole. (The two results of these test points are listed in Table 7-13 for reference.) The drill hole diameter in claystone was too large to perform the test. The results are summarized as follows:

- The average value of deformation Modulus of coarse-grained sandstone even in weathered part is large, about 41,000 kgf/cm^2 because there are few cracks in the bedrock and that in the part including claystone patch is about 10,000 kgf/cm^2.

Yielding are only observed in the test data at the shallow points in the outlet site. These results clearify that the geologic conditions of the bedrock of siltstone is not so bad.

- The results for each rock types are summarized in Table 7-14 and Fig. 7-7 from the viewpoint of the size of rock-forming grains. The deformation modulus tends to increase as the size of the rock-forming grains increases.

Table 7-13 (1) Results of Drill Hole Deformation Test

Drill Hole No.	El. of Drill Hole Head (m)	Test Depth (m)	Geology	Rock Classification, Evaluation		Yield Pressure Py (kgf/cm²)	Deformation Modulus D (kgf/cm²)		Secant Elastic Modulus Es (kgf/cm²)	
				W, H, C	RE			Stress Range		Stress Range
DHU-1	632.14	46.2	c-ss	4, 3-4, 2	H3	90 <	23,000	20~90	50,000	0~90
DHU-1	632.14	50.45	clayey f-ss	2, 3, 2-3	H2	90 <	28,000	25~90	94,000	0~90
DHU-1	632.14	66.5	sts (sheared)	2-3, 4, 5	S3	90 <	19,000	25~90	52,000	0~90
DHU-1	632.14	71.7	sts	1, 3-4, 2-3	S2	82 <	18,000	22~82	61,000	0~82
DHU-1	632.14	81.0	sts (sheared)	1, 4, 3	S3	85 <	11,000	20~85	43,000	0~85
DHU-4	638.30	8.7	c-ss	3, 2, 2	H1	55 <	60,000	15~55	100,000	5~55
DHU-4	638.30	23.0	c-ss	2, 1-2, 1	H1	55 <	300,000<	15~55	300,000<	5~55
DHU-4	638.30	24.4	c-ss with cls layers	3, 3-4, 3-4	H3	55 <	9,300	15~55	31,000	5~55
DHU-4	638.30	34.3	c-ss	3, 2-3, 2	H2	55 <	40,000	15~55	200,000	5~55
DHW-1	631.05	82.0	silty f-ss	1, 3-4, 2-3	H3	50 <	13,000	15~50	50,000	0~40
DHW-1	631.05	95.5	alt of f-ss & sts	1, 3, 1	H2	87.5<	40,000	12.5~87.5	100,000	0~87.5
DHW-1	631.05	113.0	sandy sts	1, 3, 2	S2	85 <	17,000	10~85	70,000	0~85
DHW-1	631.05	115.7	sts	1, 3, 1-2	S2	87.5<	19,000	12.5~87.5	100,000	0~87.5
DHW-1	631.05	124.35	alt of f-ss & sts	1, 3, 2-3	H2	87.5<	40,000	12.5~87.5	90,000	0~87.5
DHW-1	631.05	127.9	c-ss	1, 1-2, 1	H1	85 <	50,000	10~85	200,000	0~85
DHW-1	631.05	133.5	sandy sts	1, 3, 1	H2	82 <	23,000	22~82	57,000	2~82
DHW-1	631.05	145.3	c-ss with clay patches	1, 3-4, 2	H3	82.5<	14,000	22.5~82.5	26,000	0~82.5
DHW-1	631.05	165.6	c-ss	1, 1, 1	H1	82 <	70,000	7~82	400,000	7~82
DHW-1	631.05	187.0	sts	1, 3-4, 2-3	S2	80 <	11,000	20~80	19,000	0~80
DHW-1	631.05	193.0	alt of sts & silty f-ss	1, 3, 3	H2	85 <	61,000	25~85	200,000	0~85

ss : sandstone　c- : coarse-grained　f- : fine-grained　sts: siltstone　cls: claystone
alt: alternation　W : weathering　H : hardness　C : crack spacing　RE : rock evaluation

Table 7-13 (2) : Results of Drill Hole Deformation Test

Drill Hole No.	El. of Drill Hole Head (m)	Test Depth (m)	Geology	Rock Classification. Evaluation		Yield Pressure Py (kgf/cm²)	Deformation Modulus		Secant Elastic Modulus	
				W . H . C	RE		D (kgf/cm²)	Stress Range	Es (kgf/cm²)	Stress Range
DHW-2	422.83	130.5	sandy sts	1 , 2-3, 1-2	S2	50 <	* 63,000	8~33	*150,000	3~33
DHW-2	422.83	155.0	sts	1 , 3-4, 3	S2	80 <	* 44,000	20~80	*400,000	0~80
DHT-1	316.08	74.3	sts	1 , 3 , 1	S2	90 <	23,000	20~90	——	—
DHT-1	316.08	83.5	sts	1 , 3 , 2-3	S2	85 <	23,000	15~85	110,000	0~85
DHT-1	316.08	91.3	silty f-ss	1 , 2-3, 1	H2	90 <	49,000	20~50	82,000	0~50
DHT-1	316.08	102.3	alt of f-ss & sts	1 , 2-3, 2-3	H2	87 <	32,000	22~87	140,000	0~87
DHT-1	316.08	103.8	f-ss	1 , 2 , 3	H1	85 <	46,000	20~85	140,000	0~85
DHT-1	316.08	123.3	sts	1 , 3 , 2-3	S2	85 <	*170,000	15~85	*400,000<	0~85
DHT-1	316.08	135.0	sts	1 , 3 , 1-2	S2	85 <	* 95,000	25~85	*400,000<	0~85
DHT-1	316.08	156.0	sts	1 , 3 , 1-2	S2	82 <	*150,000	22~82	*400,000<	2~82
DHT-2	290.00	17.5	sts	3 , 4-5, 5	S3	16 <	1,500	4~14	4,000	4~14
DHT-2	290.00	24.3	sandy sts	2 , 3-4, 2	S3	94 <	8,300	19~94	29,000	4~94
DHT-2	290.00	35.0	f-ss	2-3, 1-2, 1	H1	94 <	80,000	19~94	500,000	4~94
DHT-2	290.00	47.0	sts	1 , 3-4, 1	S2	92 <	25,000	17~92	60,000	2~92
DHT-2	290.00	62.0	silty f-ss	1 , 3 , 1	H2	91 <	40,000	16~91	500,000<	1~91
DHT-3	276.84	18.5	f-ss	3 , 3 , 1	H2	143 <	8,900	28~63	60,000	3~63
DHT-3	276.84	24.0	sts	1 , 3-4, 3	S2	67	17,000	17~62	100,000	2~42
DHT-3	276.84	31.0	sts	1 , 3-4, 3	S2	95 <	6,300	15~40	50,000	0~40
DHT-3	276.84	32.5	sts	1 , 3-4, 3	S2	65	9,400	15~60	70,000	0~40
DHT-3	276.84	39.3	sandy sts	1 , 3-4, 3	S2	90 <	18,000	15~90	200,000	0~40
DHT-3	276.84	43.7	sts with f-ss	1 , 3 , 1	S1	90 <	*100,000	15~90	*200,000<	0~40

ss : sandstone c- : coarse-grained f- : fine-grained sts: siltstone cls: claystone
alt: alternation W : weathering H : hardness C : crack spacing RE : rock evaluation
* : large error

Table 7-14 Summary of Drill Hole Deformation Test

Geology		Rock Classification and Rock Evaluation *		Data Qt.	Deformation Modulus D (kgf/cm²)		Yield Pressure Py (kgf/cm²)
Rock Name	Description	W , H , C	RE		Range	Mean	
coarse-grained sandstone	fresh part	1-2, 1-2, 1	H1	3	50,000 ~ 300,000<	140,000<	55 <
	weathered part	3-4, 2-4, 2	H2	3	23,000 ~ 60,000	41,000	55 <
	including claystone patches	1-3, 3-4, 2-4	H3	2	9,300 ~ 14,000	12,000	55 <
fine-grained sandstone	Fresh or slightly weathered part	1-3, 1-2, 1-3	H1	2	46,000 ~ 80,000	63,000	85 <
	weathered part	3 , 3 , 1	H2	1	8,900	8,900	143 <
alternation of sandstone and siltstone	fresh part	1 , 2-3, 1-3	H2	4	32,000 ~ 61,000	43,000	85 <
silty fine-grained sandstone	fresh part	1-2, 2-4, 1-3	H2	4	13,000 ~ 49,000	32,000	50 <
sandy siltstone	fresh part	1 , 3-4, 1-3	S2	3	17,000 ~ 23,000	19,000	82 <
	weathered part	2 , 3-4, 2	S2	1	8,300	8,300	94 <
siltstone	fresh part	1 , 3-4, 1-3	S2	11	6,300 ~ 25,000	17,000	65, 67 and 78.5<
	weathered part	3 , 4-5, 5	S3	1	1,500	1,500	16 <

* see Table 7-19, 7-20 ; W : weathering H : hardness C : crack spacing RE: rock evaluation

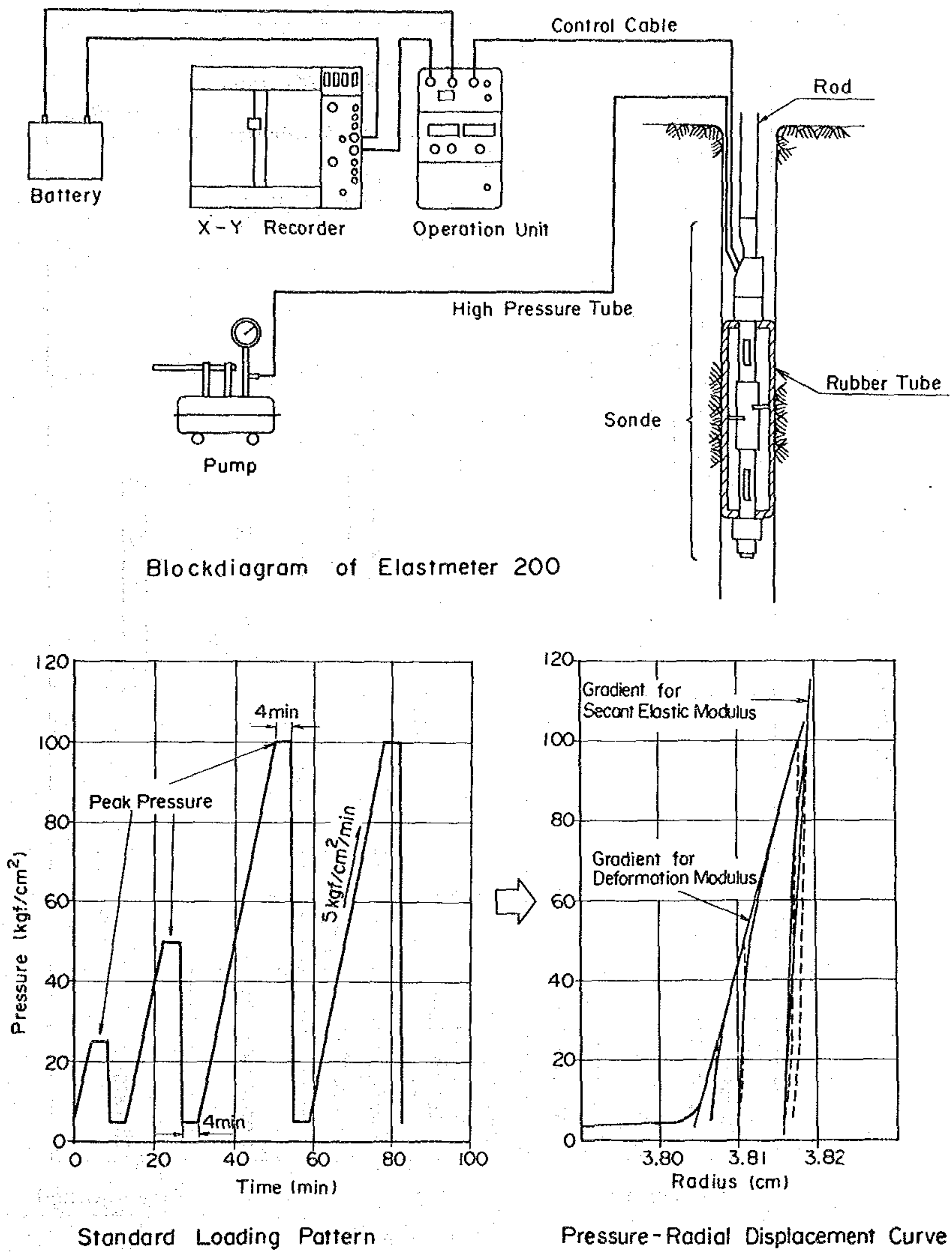


Fig. 7-6 Outline of Drill Hole Deformation Test

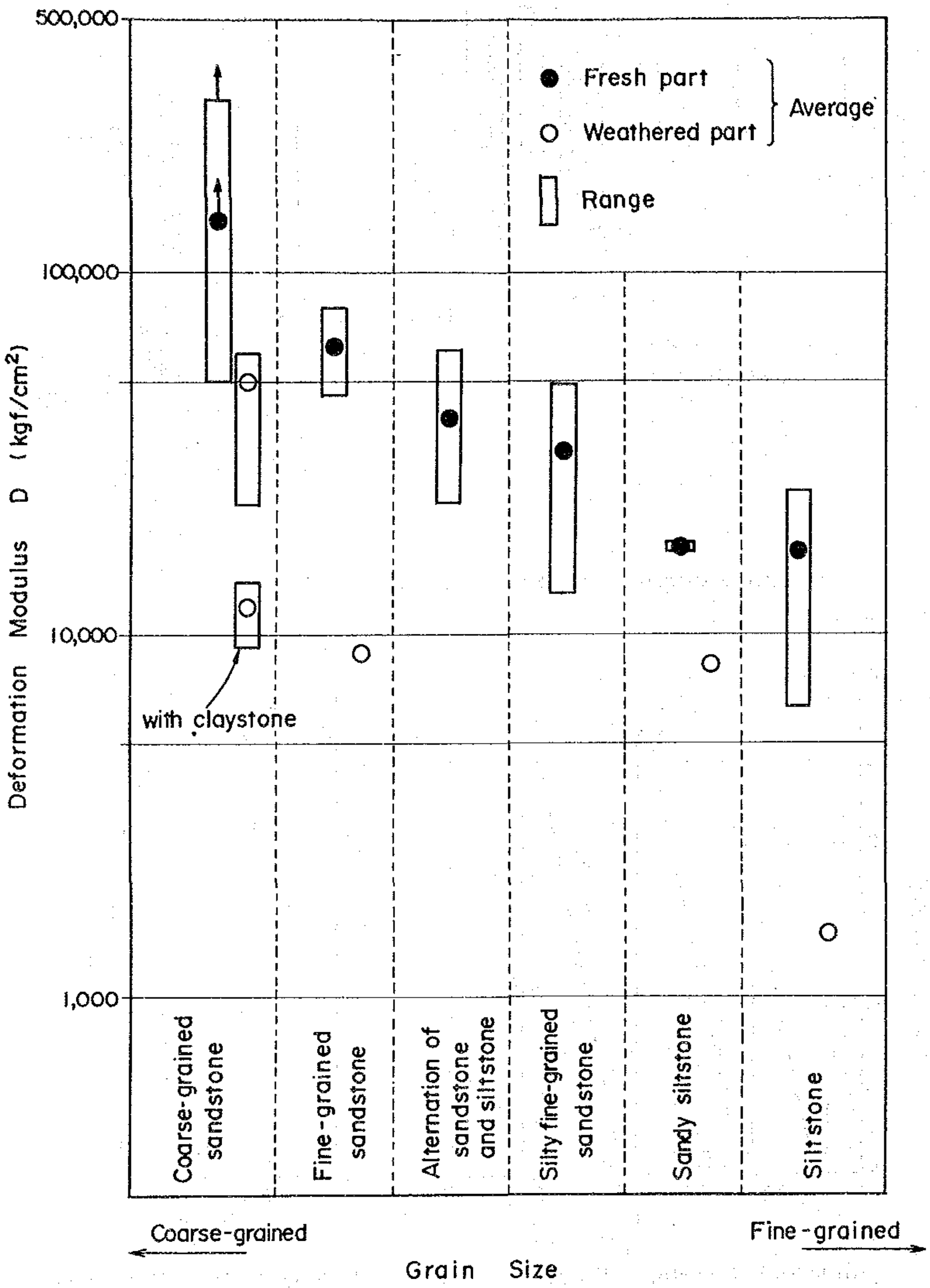


Fig. 7-7 Relation Between Grain size and Deformation Modulus

7.11 Laboratory Test

7.11.1 Drill Core Test

(1) Test Items, Quantity and Methods

Test items, quantity and methods of the laboratory test of samples from drill cores are listed as follows.

Test Item	Quantity	Method
Specific Gravity, Absorption Test	9	ASTM Standard C-127
Uniaxial Compression Test (including natural water content and dry density)	35*	ASTM Standard D-2938
Pulse Velocity Test	19*	ASTM Standard D-2845

* 1 ~ 6 specimens for each sample

(2) Results

The test results are shown in Table 7-15, 7-16. The detailed test results are attached in Appendix-A. The test results are summarized as follows:

- The dry density decreases as the grain size of rock increases. (except for claystone)

- The absorption increases as the grain size of rock increases. (except for claystone)

- The P-wave velocity of highly weathered claystone is about 1.0 km/s and that of fresh coarse-grained sandstone is about 3.8 km/s. These values roughly correspond to the 2nd layer velocity, 0.6 - 1.0 km/s and the 4th layer velocity, 4.0 ~ 4.4 km/s in the results of the seismic prospecting respectively.

- The uniaxial compressive strength generally decreases as the grain size of rock decreases except that the strength of coarse-grained sandstone is smaller than that of fine-grained sandstone.

- The uniaxial compressive strength of siltstone averages about 300 kgf/cm^2, however, special attention should be paid to the point that the test samples were collected from the part where the cores were relatively hard and not slaked.

7.11.2 Undisturbed Sample Test

(1) Test Item, Quantity and Method

Triaxial compression test (ASTM Standard D-2850, $\overline{CU}$ test) was performed for the three undisturbed samples from the depth of about 5 m in the test pits, PU-1, 3, 4.

(2) Results

The test results are shown in Table 7-17. The detailed test data are attached in Appendix-A.

The cohesion ($\overline{C}$) and internal friction angle ($\overline{\Phi}$) under effective stress condition are about 0.3 ~ 0.4 kgf/cm^2 and 27.4 ~ 32.7° respectively. The cohesion of the sample from PU-4 is small probably because of its high content of fine particles as shown in Table 7-22.

The uniaxial compressive strength (σ_c) of highly weathered claystone is estimated to be 1 kgf/cm^2 by the following equation on the basis of the data obtained in this test.

$$\sigma_c = \frac{2\overline{C}\cos\overline{\Phi}}{1 - \sin\overline{\Phi}}$$

This value is much smaller than the value of claystone sample (16 kgf/cm^2) from the depth of 14.3 ~ 16.8 m in drill hole DHU-5. (See Table 7-15) From these results, it is seen that the values of strength in the same claystone are rather different as weathering is intensive near the ground surface.

Table 7-15(1) Laboratory Test Results of Drill Cores

Drill Hole No.	Sample Depth (m)	Geology	Rock Classification, Evaluation		Water Content (%)	Dry Density (g/cm³)	P-Wave Velocity (m/s)	Uniaxial Compressive Strength (kgf/cm²)
			W , H	RE				
DHU-1	12.10- 13.30	cls	3-4, 5	S3	3.87	2.18	—	31
DHU-1	61.00- 62.00	silty f-ss	1-2, 2	H1	0.41	2.48	—	548
DHU-1	73.20- 74.20	sts	1 , 3	S2	3.49	2.48	627	223
DHU-1	87.00- 87.45	f-ss	1 , 1-2	H1	0.94	2.57	3,210	850
DHU-2	17.20- 17.90	cls	2-3, 4	S3	0.99	1.96	1,230	17
DHU-3	10.70- 11.00	c-ss	3 , 1-2	H1	0.15	2.31	3,830	562
DHU-3	15.70- 16.00	c-ss	3 , 1	H1	0.11	2.31	3,970	635
DHU-3	24.80- 25.00	c-ss	3 , 1	H1	0.05	2.31	3,660	508
DHU-3	36.00- 36.45	c-ss with cls	3-4, 3-4	H3	0.12	2.10	3,830	275
DHU-4	18.00- 19.00	c-ss	1-2, 1	H1	0.37	2.31	4,170	769
DHU-4	34.00- 34.70	c-ss	3 , 1-2	H1	0.22	2.27	4,320	664
DHU-4	37.40- 37.60	c-ss	3-4, 2-3	H2	1.24	1.96	3,440	228
DHU-5	6.05- 7.45	c-ss	4 , 2	H2	0.11	2.22	2,440	351
DHU-5	14.30- 16.80	cls	5 , 5	S3	0.78	1.88	1,070	16
DHW-1	154.00-155.00	c-ss	1 , 1	H1	0.92	2.42	2,780	718
DHW-1	223.30-223.60	sts	1 , 3	S2	3.02	2.50	—	306
DHW-2	72.55- 72.90	sts	1 , 3	S2	2.68	2.52	—	272
DHW-2	130.00-131.00	sandy sts	1 , 2-3	S1	1.23	2.56	—	583

ss : sandstone c- : coarse-grained f- : fine-grained
sts: siltstone cls: claystone
W : weathering H : hardness RE : rock evaluation

Table 7-15(2) Laboratory Test Results of Drill Cores

Drill Hole No.	Sample Depth (m)	Geology	Rock Classification, Evaluation W , H	RE	Water Content (%)	Dry Density (g/cm³)	P-Wave Velocity (m/s)	Uniaxial Compressive Strength (kgf/cm²)
DHW-2	150.15-150.30	sandy s'ts	1 , 3	S2	0.41	2.62	—	460
DHW-2	164.80-164.95	sts	1 , 3	S2	0.58	2.56	—	219
DHW-2	173.20-174.00	sandy sts	1 , 2-3	S1	0.55	2.62	3,370	772
DHW-2	207.20-207.55	sts	1 , 3	S2	3.05	2.53	2,450	308
DHW-2	222.00-223.00	f-ss	1 , 1-2	H1	0.90	2.50	2,960	727
DHW-2	236.15-236.40	sts	1 , 3	S2	1.77	2.60	—	567 *
DHW-2	244.20-244.35	sts	1 , 3	S2	2.35	2.58	—	335
DHT-1	75.10- 76.55	sts	1 , 3	S2	2.88	2.52	2,770	265
DHT-1	104.00-104.95	f-ss	1 , 1	H1	1.24	2.40	2,670	710
DHT-1	112.10-112.40	sts	1 , 3	S2	3.05	2.51	—	325
DHT-1	114.30-114.50	sts	1 , 3	S2	2.64	2.56	—	332
DHT-1	133.50-135.00	sts	1 , 3	S2	2.19	2.58	—	327
DHT-2	56.00- 57.50	sandy sts	1 , 3	S2	1.55	2.59	—	481
DHT-2	66.00- 67.00	f-ss	1 , 2	H1	1.17	2.53	—	1,148
DHT-3	22.00- 23.00	f-ss	3 , 3	H2	1.43	2.46	—	729
DHT-3	43.00- 44.00	silty f-ss	1 , 2-3	H2	1.15	2.59	—	934
DHT-3	49.00- 50.00	silty f-ss	1 , 2-3	H2	1.25	2.57	2,300	1,083

* exceptional value for siltstone

ss : sandstone c- : coarse-grained f- : fine-grained
sts: siltstone cls: claystone
W : weathering H : hardness RE : rock evaluation

Table 7-15(3) Laboratory Test Results of Drill Cores

Drill Hole No.	Sample Depth (m)	Geology	Rock Classification, Evaluation		Bulk Specific Gravity, Dry	Bulk Specific Gravity, Saturated	Bulk Specific Gravity, Apparent	Absorption (%)
			W , H	RE				
DHU-1	61.00- 62.00	silty f-ss	1-2, 2	H1	2.47	2.55	2.70	3.45
DHU-3	36.00- 36.45	c-ss with cls	3-4, 2	H3	2.17	2.26	2.40	4.35
DHU-4	18.00- 19.00	c-ss	1-2, 1	H1	2.37	2.44	2.53	2.60
DHW-1	154.00-155.00	c-ss	1 , 1	H1	2.41	2.49	2.63	3.46
DHW-2	222.00-223.00	f-ss	1 , 1-2	H1	2.49	2.56	2.69	3.06
DHT-1	104.80-104.95	f-ss	1 , 1	H1	2.46	2.55	2.68	3.34
DHT-2	66.00- 67.00	f-ss	1 , 2	H1	2.54	2.60	2.69	2.20
DHT-3	43.00- 44.00	silty f-ss	1 , 2-3	H2	2.57	2.63	2.72	2.07
DHT-3	49.00- 50.00	silty f-ss	1 , 2-3	H2	2.60	2.64	2.70	1.53

ss : sandstone c- : coarse-grained f- : fine-grained
sts: siltstone cls: claystone
W : weathering H : hardness RE : rock evaluation

Table 7-16 Summary of Drill Core Test

Geology: Rock Name	Geology: Description	Rock Classification W, H	Rock Evaluation	Data Qt.	Dry Density (g/cm³)	P-Wave Velocity (m/s)	Uniaxial Compressive Strength (kgf/cm²)
coarse-grained sandstone	fresh part	1-3, 1-2	H1	6	2.32	3,790	643
	weathered part	3-4, 2-3	H2	2	2.09	2,940	290
	including claystone	3-4, 3-4	H3	1	2.10	3,830	275
fine-grained sandstone	fresh part	1, 1-2	H1	4	2.50	2,950	859
	weathered part	3, 3	H2	1	2.46	—	729
silty fine-grained sandstone		1-2, 2-3	H1-2	3	2.55	—	855
sandy siltstone		1, 2-3	S1	2	2.59	3,370	678
		1, 3	S2	2	2.61	—	471
siltstone		1, 3	S2	11	2.54	2,610	317
claystone	slightly～moderately weathered part	2-4, 4-5	S3	2	2.07	1,230	24
	highly weathered part	5, 5	S3	1	1.88	1,070	16

ss : sandstone c- : coarse-grained f- : fine-grained
sts: siltstone cls: claystone alt: alternation
W : weathering H : hardness C : crack spacing RE : rock evaluation

Table 7-17 Triaxial Test Result of Undisturbed Samples of Test Pits

Pit No.	Sample Depth (m)	Geology [Rock Evaluation]	Water Content (%)	Dry Density (g/cm³)	Shear Strength ($\overline{CU}$ test)	
					Cohesion $\overline{C}$ (kgf/cm²)	Friction Angle $\overline{\phi}$ (°)
PU-1	4.8	highly weathered claystone [S3]	14.10-14.69	1.880 -1.920	0.36	32.6
PU-3	5.0	highly weathered claystone [S3]	13.28-15.11	1.785 -1.910	0.30	32.7
PU-4	4.9	highly weathered claystone [S3]	12.57-14.56	1.712 -1.772	0.35	27.4

7.12 Mineralogical and Chemical Analyses of Drill Cores

(1) Items, Quantity and Purpose of Analyses

The samples, items, quantity and purpose of analyses are shown in Table 7-18. Five samples from the drill cores of the upper reservoir site and six samples from the drill cores of the waterway route were mineralogically analyzed by thin section method and X-ray diffraction method and chemically analyzed by flourescent X-ray methods.

(2) Results

The results are shown in Table 7-18. The detailed analyses data are attached in Appendix-A. The results of analyses are summarized as follows:

- Residual soil (laterite) is mainly composed of quartz, hematite and kaolin.

- The mineral formed by weathering in residual soil and coarse-grained sandstone is kaolin.

- Fine-grained sandstone is cemented by chlorite.

- Claystone is composed of kaolin, quartz and sericite.

- Siltstone is mainly composed of quartz, plagioclase, sericite and chlorite. Red siltstone contains large amount of hematite and attains Fe_2O_3 content of about 7%, while the part containing little hematite looks green because of chlorite. Calcite and/or gypsum are often contained and the CaO content of some part attains to about 8%. Expansive clay mineral such as montmorillonite is not found in siltstone.

Table 7-18 Results of Mineralogical and Chemical Analyses of Drill Cores

Sample No.	Sampling Point: Drill Hole No.	Sampling Point: Depth (m)	Geology	Items of Analyses: Thin Section	Items of Analyses: X-ray Diffraction	Items of Analyses: Chemical Composition	Purpose of Analyses	Constituent Minerals ※: Quartz	Plag.	Hemat.	Seric.	Chlor.	Calc.	Gypsum	Kaolin	Remarks
SU-1	DHU-3	0.5	residual soil (laterite)		○#, ##		identification of constituent minerals of lateritic crust and weathered rock	◎		++++	++			+	+++	Gibbsite is not identified.
SU-2	DHU-3	0.5	nodule in residual soil (lateritic crust)		○#			++++		◎						
SU-3	DHU-3	5.5	weathered claystone		○#, ##			◎		++	+++			++	++++	
SU-4	DHU-4	15.0	medium-grained sandstone	○	○#		observation of texture and cement material	◎			+++				++++	Cement material is kaolin, which may have been originally chlorite.
SU-5	DHU-4	26.9	claystone		○#, ##		identification of constituent minerals	○			+++				◎	
ST-1	DHT-2	57.8	fine-grained sandstone with calcareous spots	○			identification of calcareous spots	◎	○	++	+++	++	++++			Calcareous spots may be calcareous algae.
ST-2	DHT-3	29.5	siltstone (red, slaking)		○#, ##	○*	identification of constituent minerals, identification of green clay minerals	◎	+++	+++	+++	+++	+++			
ST-3	DHT-2	53.8	silty sandstone (green, slightly slaking)		○#, ##	○**		◎	○		+++	+++	○			Green clay mineal is chlorite.
ST-4	DHW-2	194.0	siltstone (red and green, slightly slaking)	○	○#, ##	○*		◎	++++	++	+++	+++	○	++		
ST-5	DHW-2	220.8	fine-grained sandstone (gray, not slaking)	○	○#		observation of texture and cement material	◎	++++	+	+++	+++	+++			Cement material is chlorite and calcite.
ST-6	DHW-2	232.8	siltstone (green, not slaking)		○#, ##		identification of constituent minerals	◎	++++		++++	+++		++		

bulk analysis
clay fraction analysis

* : SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, H_2O^-, H_2O^+
**: Fe_2O_3, FeO, MgO

※ Plag.: Plagioclase Hemat.: Hematite Seric.: Sericite
Chlor.: Chlorite Calc.: Calcite
relative quantity : abundant ⇦ ◎ ○ ++++ +++ ++ + ⇨ trace

Sample No.	Chemical Composition Oxides (wt%): SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	H_2O^+
ST-2	53.96	0.76	17.30	7.03	1.05	0.04	3.25	2.01	2.02	3.76	0.17	1.78	5.07
ST-3	—	—	—	1.21	0.63	—	2.24	—	—	—	—	—	—
ST-4	54.05	0.62	13.32	4.36	0.83	0.15	2.56	7.92	1.85	2.57	0.13	1.26	4.00

Fe^{2+}, Fe^{3+} : wet process chemical analysis
the others : flourescent X-ray analysis