5.2 Geological Investigations

As geological investigations necessary for the Master Plan on this Project, the items below were carried out by the JICA Survey Team with the cooperation of ELECTROPERU, from July 1984 to July 1985. The results of these investigations comprise the data sources for writing this chapter.

1) Aerial and Field Reconnaissances

From July 19 to July 23, 1984, primary aerial and field reconnaissances were carried out by cessna planes covering an area along the Ene River and by canoes along the river channel from the Tambo Puerto Prado site to approximately 15 km upstream of the Ene Paquitzapango site.

Secondly, from October 30 to November 5 of the same year the depths of water of the Rio Tambo at the Tambo Puerto Prado site and of the Rio Ene at the Ene Paquitzapango site were measured by sonic sounding equipment, while at the same time detailed examinations of drilled cores at the Tambo Puerto Prado and Ene Paquitzapango sites were made at the ELECTROPERU camp in Puerto Ocopa.

Thirdly, a brief reconnaissance using canoes were done from Cutivireni to Sumabeni along the Ene River on 27 and 28 June, 1985.

2) Geological Aerial-Photo Interpretation

From the beginning of August to the beginning of October, 1984, a photo geologist stayed in Peru and carried out photo-geological interpretations by stereo glass and field reconnaissances for confirmation. The photo geologist made confirmations in the field by canoe along the main flow channel from downstream of the Tambo Puerto Prado site to upstream of the Ene Paquitzapango site, and on foot and by automobile from Puerto Ocopa to Satipo. He also made aerial reconnaissances of the various project sites by Cessna plane.

The aerial photographs used for the interpretations had been taken by SAN (Servicio Aerofotografico Nacional), a Peruvian government agency, and comprised a total of 342 sheets (scales: 1/40,000, 1/60,000, and 1/80,000). These photographs cover the areas along the entire length of the Ene River and the downstream part of the Apurimac River.

The index map and lists of the aerial photographs used in interpretations are given in Appendix A-2 [1] and Appendices A-2 [2] and [3], respectively.

3) Seismic Prospecting

Seismic prospecting by the refraction method was carried out at the Tambo Puerto Prado and Ene Paquitzapango sites from the end of August to the end of October, 1984. The numbers of seismic traverses made at the two sites are as shown in Table 5-1.

Table 5-1 Total Length of the Seismic Traverses at the Ene River Projects in 1984

Site	No.s of Seismic Traverse	Total Length
Tambo Puerto Prade	5 Traverses	3,960 m
Ene Paquitzapango	4 Traverses	1,070 m
Grand Total	9 Traverses	5,030 m

These prospecting works were carried out by a Peruvian firm (Jose E. Arce Exploration Geophysicist Survey) and during the period of prospecting, an exploration engineer was dispatched from the JICA Survey Team as a supervisor. The results of the prospecting were compiled in the form of a report by the Peruvian firm, which was submitted to the JICA Survey Team.

4) Exploration by Core Drilling

Core drilling was performed at the Tambo Puerto Prado and Ene Paquitzapango sites from the middle of August to the beginning of November, 1984 by a Peruvian drilling company (Geotec S.A.) under the supervision of two field engineers dispatched by the JICA Survey Team. Permeability tests in drillholes were carried out at the same time. The lengths drilled and the numbers of permeability tests at the two sites are shown in Table 5-2.

Table 5-2 Total Length Drilled and Numbers of Permeability Test at the Ene River Projects in 1984

Site	No.s of Drill Holes	Total Length Drilled	No.s of Permeability Test
Tambo Puerto Prado	3 Holes	116 m	17 Sections
Ene Paquitzapango	1 Hole	50 m	10 Sections
Grand Total	4 Holes	166 m	27 Sections

The records of these drilling works and the results of the permeability tests have been made up into a report by the Peruvian contractor under the supervision of the JICA Survey Team.

Boring logs, core photographs,and permeability test data of these drilling works are shown in Appendices A-2 [5] to A-2 [9].

5) LANDSAT Imagery Analysis and Interpretation

As previously stated, LANDSAT imagery analyses were performed by the JICA Survey Team in Japan from June to October, 1985 as a means of supplementing the sparseness of topographical and geological information. The LANDSAT images of this area reflect the topographical and geological characteristics of the area well, and the information obtained from the images was extremely useful in clarifying the outlines of the general topography and geology. The data sources and scope of analysis work of the LANDSAT imagery described in this report are given in Appendix A-2 [11].

6) Topographical and Geological Analyses

A comprehensive study of the abovementioned geological investigation results and the existing geological data listed at the end of this chapter was carried out in Japan from December 1984 to the end of October, 1985. Following this, the JICA Survey Team visited Peru from the end of June to the first part of July 1985 and reported interim results to ELECTROPERU. As a consequence, a part of the geological analysis work was modified, and all work was completed by the middle of November 1985.

In particular, the results of seismic prospecting and core drilling investigations of the Tambo Puerto Prado and Ene Paquitzapango sites were carefully cross-checked, and the physical properties of rock and thicknesses of the sand-gravel deposits in the riverbeds of the two sites were examined.

5.3 General Geomorphology and Geology of Project Area

(1) Geographical Location

The Andes Mountain System (CORDILLERA DE LOS ANDES) which runs along the western fringe of South America and forms the backbone of the continent has a directional trend of NW-SE in Peru. Its eastern border is adjacent to the vast Amazon Plain (LLANURA AMAZONICA) while the western border comprises a high mountain range (CORDILLERA OCCIDENTAL) and directly drops to the Pacific Ocean. The Andes Mountain System topographically is broadly divided into the West Andes, Central Andes, and East Andes, and these collectively are called the Peruvian Andes. Further to the east there is a Sub-Andes (CORDILLERA SUBANDINA) having the same directional trend.

The project area, physiographically, is in the basin of the Ene River which runs between two of the abovementioned mountain elements, namely, the East Andes and the Sub-Andes, and comprises the upstream stretch of the Ucayali River, the largest tributary of the Amazon River. This project area is located approximately 330 km east-northeast from Lima, the capital city of Peru, which is located close to the Pacific Ocean coast in the central part of the country.

The Ene River has a total length of approximately 170 km, and while meandering locally, flows on the whole in a north-northwest direction. At the downstream end the Ene merges with the Perene River to become the Tambo River. The Tambo River changes its direction of flow abruptly and on the whole flows east. The upstream end of the Ene River is the confluence of the Apurimac River, which flows roughly north-northeast, and the Mantaro River, which flows east coming from the left-bank side.

Of the project sites made the objects of the present investigations, the downstreammost Tambo Puerto Prado site is located immediately downstream of the confluence of the Perene and Ene Rivers (upstreammost part of the Tambo River) and in order toward the upstream there are the Ene Paquitzapango site approximately 50 km upstream from the confluence, the Ene Cutivireni site approximately 100 km upstream, and the Ene Sumabeni site approximately 150 km upstream.

(2) General Geomorphology

Seen from the aspect of height the riverbed of the Ene River ranges between elevations of approximately 280 m and approximately 450 m. The river banks on both sides from hilly mountainlands of elevations approximately between 500 and 800 m or mountain masses of elevation around 1,000 m, and these after a number of large and small undulations eventually connect to the previously-mentioned two dominant mountain ranges.

According to interpretations of aerial photographs and LANDSAT images, the outline of the topography of the project area, namely, the Ene River Basin, is characterized by the existence of the previously-mentioned two major mountain ranges and a spur, and further, a number of longitudinal valleys *1) developed between the mountain ranges and a number of transverse valleys *2) crossing the spur, thus presenting a topography with remnants of a youth stage.
The general trend of the physiography along the Ene River is that valley width becomes relatively narrowed from upstream to downstream, along with which the surrounding mountain features become slightly more rugged the further downstream.

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*1) A valley which runs parallel to manifest mountain chains; the term is often applied to a valley which is parallel to the strike of the rock strata.

*2) A valley which cuts across manifest mountain ranges.

Regarding the topography of each project site, from the downstream-most Tambo Puerto Prado site to the upstreammost Ene Sumabeni site, every site is located at what is geomorphologically transverse valley, but as stated above, the valley widths at the upstream Cutivireni and Sumabeni sites are larger than at the downstream Paquitzapango site, and moreover, both banks are gently sloped.

(3) Geomorphological Features Interpreted by Aerial Photographs and LANDSAT Imagery

Here, a number of notable landforms from among the geomorphological features extracted from interpretations of aerial photographs and LANDSAT images of this project area are explained, while with regard to tectonic landforms having close reltaions to geological structures, they will be described in the sections on geology to follow.

1) Landslide *3)

The bedrock of this area consists of sedimentary rocks and a few large-scale landslides are seen in the area. At least, there appear to be no large-scale ones distinctly suggesting possibilities of sliding in the future.

When the aerial photographs are interpreted very carefully, there are a few (less than ten) places here and there that possibly are old landslides. However, in the present state, except for a part of their scars, they are coverd with vegetation and appear to be stable. Geomorphologically, there are many anticlinal ridges seen in this area, and since the strikes and dips of slopes and strata at the sides of these ridges coincide, landslides are apt to occur when the skirts are eroded. However, there are few landslides on the whole and this is probably due to the youngness of the cycle of erosion.

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*3) The term "landslide" as used here is for comparatively large-scale mass movements. In this type of movement, sliding takes place on a definite plane which may be a structural plane, e.g., bedding, joint, schistosity, etc., or a curved sheared plane, giving rise to slumps such as found in clays.

2) Slope Failure *4)

At the midstream to upstream area of the Ene River Basin there are slope failures distributed indicating a trend to be somewhat concentrated at parts. The slope failures are distributed at midslope and higher at the right-bank mountains in the midstream area, and at comparatively low places at both banks in the upstream area. Slope failures in the downstream area are very small in number compared with the midstream and upstream areas. These slope failures, so far as seen in aerial photographs, are all of small scale (estimated sized mostly less than 50 m in both height and width), and some of these are thought to have been triggered by man through agricultural activities.

3) Karst Landform

Since formations including limestone and calcareous rocks are distributed in the project area, karst landforms were interpreted with special care and as a result, typical karst landforms such as large-scale sinkholes and karrenfelds were not seen. However, there were places where small depressions were noticed at the ground surface. These depressions appeared to be circular or elliptical as seen in aerial photographs and northeast and south of the Ene Paquitzapango site there were a number which showed diameters of about 100 m, but most of the others were less than 50 m in diameter. These areas are almost all covered by vegetation. Whether these are actually sinkholes cannot be ascertained other than by surface reconnaissances, but in this report they will tentatively be referred to as sinkholes.

These sinkholes are of small scale on the whole and are distributed in slightly large numbers along the midstream to downstream areas of the Ene River at places of rlatively high elevations (approximately EL. 600 m and higher), at the right-bank side more than the left-bank side.

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*4) The term "slope failure" in this report is applied to a gradual or rapid and relatively small-scale downward slope movement of soil or rock under gravitational stress.

Even if these are actually sinkholes, they are all distributed at palces amply above the surface of the river, while seen from the point of view of geological structure to be described later, it is inconceivable that they will greatly restrict the hydroelectric development scheme for the Ene River. However, in the sense of assuring safety, it will be necessary for further detailed investigations to be made in the future.

4) Terraces

The erosional agency of the Ene River is extremely active and terraces formed by erosive action of the Ene River in the past remain only locally upstream of the Ene Paquitzapango site. At the present riverbed there are flood plains of relative heights under 10 m at places (especially in the vicinities of confluences of tributaries).

(4) General Geology

Geologically, stable platforms of PreCambrian time exist on the South American continent, and at the western marginal zones of these platforms there are distributions of marine and continental sediments of the Paleozoic, Mesozoic, and most of the Cenozoic. It is known that this sedimentary basin runs parallel to the present-day Andes, from the southern part of Argentina, goes through Chile and reaches as far as Venezuela. Geomorphologically, the project area is located between the Eastern Andes and the Sub-Andes as previously stated, and this area makes up a part of the abovementioned sedimentary basin. In the project area also, there are numerous strate over a long range from the Paleozoic, Mesozoic, to the Cenozoic with similar features as the geological structure seen generally in the Peruvian Andes Region.

1) Stratigraphy

According to existing geological data collected up to the present there are parts of the stratigraphy in the project area which are yet to be ascertained. This is clearly because the greater part of the project area is a montane jungle area covered by tropical or subtropical vegetation. The JICA Survey Team, with the cooperation of ELECTROPERU, was able to observe outcrops along the Ene River from the Tambo Puerto Prado site to a point approximately 10 km upstream of the Ene Paquitzapango site. On the other hand, geological maps (sclae: 1/100,000) prepared by ELECTROPERU, geological maps (scale: 1/500,000) of PETROPERU, and generally-published geological maps of Peru (Scale: 1/1,000,000) were obtained as existing geological maps concerning the stratigraphy of this area. The stratigraphy in these geological maps is generally based on similar standards. Fundamentally, the stratigraphy shown in the geological maps of ELECTROPERU was followed, with parts modified as a result of confirmations just made in the field and based on the results of newly interpreted aerial photographs and LANDSAT images, and these are given in Table 5-3.

A comparison of the stratigraphical sequence just confirmed by field investigations in the Ene River Basin and that of existing data is as shown in Table 5-4, and the thicknesses of formations at the two sites when compared with type localities are considerably small.

The bottommost rocks confirmed in the field investigation were shale and sandstone in the Tambo River Basin and these are correlative with the Permian to Carboniferous Tarma-Copacabana Group.

The overlying calcareous rocks, according to existing data, are correlative with the Triassic Pucara Formation, and large quantities of crinoids are found at the Tambo Puerto Prado site and spirifers and productus at the Ene Paquitzapango site. These fossils are considered to be Carboniferous to Permian (according to Mr. C. Rangel, INSTITIUTO DE GEOLOGIA Y MINERIA, PERU). Because of the reasons given above, it may be considered that these calcareous rocks are of the Tarma-Copacabana Group, and in this report they will be indicated independently tentatively called the Ene Formation. *5)

Overlying the Ene Formation there are thin strata of shale and marl correlative with the Sarayaquillo Formation of the Jurassic Period and siliceous sandstone correlative with the Oriente Group of the Cretaceous Period. The relation between the two is estimated to be unconformable. Above the siliceous sandstone is a thin layer of cherty marl correlative with the Chonta Formation of the Cretaceous.

Table 5-3 Stratigraphical Correlation in the Ene River Basin

Era and Period		Formations Described in ELECTROPERU's Geological Maps	Formations Described in JICA MISSION's Geological Maps
Cenozoic	Quaternary	Alluvial Deposit	River Bed Deposit
		Colluvial Deposit	Colluvial Deposit
		Alluvium Deposit	Alluvial Plane Deposit
	Tertiary	Ipururo Formation	Ipururo Formation
		Huayabamba Formation	Huayabamba Upper Formation
			Huayabamba Lower Formation
Mesozoic	Cretaceous	Chonta Formation	Chonta Formation
		Oriente Group	Oriente Group
	Jurassic	Sarayaquillo Formation	Sarayaquillo Formation
			?
	Triassic	Pucara Formation	Ene Formation
			?
Paleozoic	Permian-Carboniferous	Tarma-Copacabana Group	Tarma-Copacabana Group
	Carboniferous	Ambo Group	Ambo Group
	Silurian	Excelsior Formation	Excelsior Formation

*5) The name of "Ene Formation" is originally derived from the Geological Map of Petroperu (1/500,000 in scale, 1968), in which it is shown as the Pucara-Ene Formation of the Jura-Triassic. From a geological engineering point of view, the Ene Formation, which is comprised mainly of limestones, is separately used in this report.
As for its stratigraphical problems, further systematic studies will be necessitated.

Table 5-4 Stratigraphic Sequence of the Ene River Basin

Era and Period		Formation	Type Locality		The Ene River Basin */	
			Rock Type	Thickness	Rock Type	Thickness
Cenozoic	Quaternary	River Bed Deposit				
		Colluvial Deposit				
		Alluvial Plan Deposit				
	Tertiary	Ipurupo Formation	Mudstone Sandstone	1,600 m	Mudstone, Sandstone	800m +
		Huayabamba Upper-Formation	Reddish Sandstone Mudstone	4,000 m	Sandstone, Marl Reddish Sandstone	400 ~ 500m±
		Huayabamba Lower-Formation	Reddish Sandstone Mudstone	3,000 m	Reddish Sandstone Marl, Sandstone	300 ~ 500m±
Mesozoic	Cretaceous	Chonta Formation	Shale, Mudstone (+Marl, Limestone)	1,100 m	Cherty Marl	50m±
		Oriente Group	Quartzose Sandstone	1,800 m	Quartzose Sandstone	100m±
	Jurassic	Sarayaquillo Formation	Sandstone (+Shale, Marl)	2,000 m	Shale, Marl	50m±
	Triassic (?)	Ene Formation	Limestone (+Marl)	2,200 m	Limestone, Marl	200m+
Paleozoic	Permian	Tarma-Copacabana Formation	Limestone, Shale	3,000 m	Shale, Marl, Sandstone	
	Carboniferous	Ambo Group	Shale (+Sandstone)	1,400 m		
	Silurian	Excelsior Formation	Shale	1,000 m		

*/ The term of "The Ene River Basin" in this Table means an area from the junction of the Ene River and the River to Sima about 3 km downstream from the junction of the Ene River and Perene River.

Table 5-5 Lithostratigraphic Unit of Tambo Puerto Prado and Ene Paquitzapang Sites

Period	Formation	Tambo Puerto Prado		Ene Paquitzapango	
		Rock Unit	Thickness	Rock Unit	Thickness
Tertiary	Ipururo Formation	—	—	Alternation of reddish sandstone and mudstone	300 m±
Tertiary	Huayabamba Upper Formation	Sandstone, marl, reddish sandstone	400 m±	Reddish sandstone, marl sandstone	500 m±
Tertiary	Huayabamba Lower Formation	Reddish sandstone, marl, sandstone	300 m±	Reddish sandstone, marl sandstone	500 m±
Cretaceous	Chonta Formation			Cherty marl	50 m±
Cretaceous	Oriente Group	Quartzose sandstone	100 m±	Quartzose sandstone	100 m±
Jurassic	Sarayaquillo Formation	Sandstone, marl	30 m_	Shale, marl	50 m_
Triassic (?)	Ene Formation	Limestone, calcareous rocks Limestone, marl	100 m+ 50 m+	Limestone, calcareous shale	200 m+
Permian -carboniferous	Tarma-Copacabana Group	Shale, sandstone	?		

Overlying the Cretaceous Chonta Formation is a thick formation consistingof reddish sandstone, marl and gray sandstone existing in unconformity, and this formation is correlative with the Tertiary Huayabamba Formation. The sequence of the reddish sandstone and the gray sandstone is not clear and requires further investigation and study. This formation shows a slight difference in geomorphologic features between interpretations of aerial photographs and LANDSAT images, and in this report the formation is divided into upper and lower layers. Overlying the Huayabamba Formation, there is distributed, again in unconformity, alternations of soft mudstone and sandstone which are correlative with the Tertiary Ipururo Formation.

The lithostratigraphic units of the Tambo Puerto Prado and Ene Paquitzapango sites are given in Table 5-5.

As Quaternary strata in the project area there are deposits comprising alluvial plains, colluvial deposits below mid-heights of mountain slopes, and riverbed deposits along river channels. These Quanternary deposits are of greatly varied particle sizes ranging from clay to boulders and are composed of unconsolidated material.

Alluvial deposits are distributed at parts of places where valley widths of principal river channels in the project area are wide, and at the vicinities of the confluences of large flow channels. Colluvial deposits are distributed at bottoms of cliffs and at skirts of slopes, contain breccia and sub-angular gravels, and slope wash, cliff debris, talus, etc. are included among these deposits.

Riverbed deposits fill the valley bottoms of principal flow channels. Peneplain deposits are also included in riverbed deposits in this report.

2) Geological Structure

What comprises a feature of this project area is the existence of folding axes in the NNW-SSE direction roughly parallel to the trend of the Andes Mountain Range. The axial planes of these folding axes roughly indicate dips to the west, and at places the crest lines of folding axes are slightly wavy. That is, culminations and depressions of anticlinal axes are seen and the geological structure of this area shows compound folds.

For convenience' sake of a explanation, the project area is divided into four districts along the Ene River, and the geological structure of each district is described as follows:

i) Downstream Area of Tambo-Puerto Prado (Tambo River Basin)

Since the area downstream of the Tambo Puerto Prado site presents a peneplain landform, the lithological characters and geological structure are not distinct from interpretations of aerial photographs and LANDSAT images, but according to existing data dome-shaped folds are seen as a whole and it is estimated that underlying formations such as the Tarma-Copacabana Group and distributed along the Tambo River. The calcareous rocks of the Ene Formation are distributed as a horizontal band at mid-slope.

ii) *Ene River Basin between Tambo Puerto Prado and* Ene Paquitzapango

A compound folding structure may be distinctly seen in this area. An anticlinal axis runs along the ridge of the west bank (left bank side) of the Ene River with mainly middle and underlying formations of the Orienta Group and others distributed as narrow bands, but to the south (upstream side), overlying formations such as the Huayabamba Formation are dominant. On the east side of this anticlinal axis there is a synclinal axis running roughly along the Ene River, and this axis is accompanied by a thrust fault parallel to it.

Gray-colored alternations of sandstone and marl are mainly exposed at the bed of the Ene River and these are estimated to belong to the Huayabamba Formation. It is possible that these gray-colored alternations resulted from eluviation or leaching of reddish sandstone and marl, and it will be necessary for this to be checked further in the field.

In the vicinity of a point approximately 11 km upstream from the confluence of the Ene and Perene rivers at the east bank (right-bank side) of the Ene River, soft, reddish mudstone and sandstone thought to be of the Ipururo Formation overlie unconformably the gray sandstone and marl, and gypsum is found at the boundary.

Anticlinal and synclinal axes alternate at the platforms on the west bank (left-bank side) of the Ene River, and it is estimated that upper strata such as the Huayabamba and Ipururo formations are mainly distributed.

iii) Ene River Midstream Basin from Ene Paquitzapango to Mision to Puerto Rico

A basin structure is formed in this area and it is assumed that overlying strata mainly the Ipururo Formation are widely distributed. Weathering has extended deep underground in this area and deep valleys of irregular dendritic patterns have been cut down.

iv) Area Upstream of Puerto Rico

The upstream basin of the Ene River from Puerto Rico up to and including the confluence with the Mantaro River is of a different geological condition from the midstream and downstream areas of the Ene River, and according to existing data, the oldest strata of the entire basin are distributed, such as the Paleozoic Tarma-Copacabana Group, Ambo Group, and Excelsior Formation. The features of these formations according to aerial photographs are that characteristics of dense and massive lithological characters are indicated, while at some places, bedding can be discerned relatively clearly.

3) Faults

The fault patterns in the project area are NWSE, NNW-SSE, NNE-SSW, E-W, and NE-SW. Of these, the ones governing the outline of the entire area's geological structure are those in the NW-SE and NNW-SSE directions. The faults in the NNE-SSW, E-W, and NE-SW directions affect local geological structures in areas along the Ene River.

Further, as results of interpretations by LANDSAT images, many lineaments (or assumed faults) with NW-SE, NNW-SSE and NE-SW, trends are predominant in the Ene River Basin and its vicinity.

In the Ene River Basin, rather continuous faults with NE-SE and NE-SW trends intersecting the Ene River are assumed between two sites, Tambo Puerto Prado and Ene Paquitzapango.

In the Apurimac River Basin, it is estimated that a relatively long fault with a NW-SE trend passes along the foot of the mountain range on the right-bank side of the Apurimac River.

5.4 Site Geology

5.4.1 Tambo Puerto Prado Site

(1) Geological Investigation Works

As geological investigations made on this site by the JICA Survey Team there have been subsurface explorations through seismic prospecting and core drilling, the locations of which are shown in Dwg.-5.4.

The quantities of seismic prospecting by the refraction method are shown in Table 5-6. The results of the prospecting are shown in Dwgs.-5.5 and -5.6.

Table 5-6 Quantitative Features of the Seismic Prospecting at Tambo Puerto Prado

Traverse	Length (m)	Geophone Stations	Shot Points	Magnetic Direction	Remarks
ST-1	600 * 300 **	900	20	N53°W	* On the right bank ** On the left bank *** Partly N28°E and N54°40'E
ST-2	1,200	1,200	21	N52°E	
ST-3	840	84	18	N7°W	
ST-4	720	72	16	N46°E ***	
ST-5	300	30	17	N48°W	
Total	3,960 m	396 Stations	92 Points		

Table 5-7 Actual Quantity of Core-drilling and Permeability Tests at Tambo Puerto Prado

Drillhole Name	Location	Elevation (m)	Length (m)	Direction	Diameter of Drillhole (cm)	Permeability Test (Times)
DT-1	Damsite on the right bank	283 */	26.0	Vertical	0m - 11.3m : ϕ = 15.24 11.3m - 20.6m : ϕ = 12.70 20.6m - 25.0m : ϕ = 11.43 25.0m - 26.0m : ϕ = 9.27 (NC)	K_1 **/ : 3 K_2 **/ : 3
DT-2	Damsite on the left bank	284 */	50.0	Vertical	0m - 8.8m : ϕ = 9.27 (NC) 8.8m - 50.0m : ϕ = 7.31 (NX)	K_1 : 3 K_2 : 2 K_3' **/ : 5
DT-3	Upstream of the damsite, on the left bank	284 */	40.0	Vertical	0m - 8.0m : ϕ = 12.7 8.0m - 27.75m: ϕ = 11.43 27.75m - 39.0m: ϕ = 9.27 (NC) 39.0m - 40.0m : ϕ = 7.31 (NX)	K_1 : 1 K_2 : 1 K_3 **/ : 5
		(Total)	(116.0)			

Notes: */ The elevation of Drillholes DT-1, -2 and -3 is roughly estimated by the aero-topographical map (1/25,000 in scale).

**/ The permeability tests, K_1, K_2 and K_3 are as follows:

K_1 : Open end method under constant water head
K_2 : Open end method under constant water head
K_3' : Open end method under variable water head
} (Le Franc Type)

K_3 : Packer method under constant water head (Lugeon Type)

The quantities of core drilling works at this site are shown in Table 5-7. The data obtained from such boring are compiled in log form and given as Appendix A-2 [5]. Permeability test records and calculation formulae for permeability values are given in Appendices A-2 [7], [8] and [9].

At this damsite, in addition to the abovementioned subsurface explorations, geological reconnaissances using 1/10,000-scale topographic maps have also been made.

(2) Topography

The Ene River flows north at its downstreammost portion and the name changes to the Tambo River after merging with the Perene River which flows east coming from the left-bank side. The damsite is located approximately 2.5 km downstream from the confluence. The Tambo River changes its course drastically from north to east in the vicinity of the damsite.

The damsite, seen from a general point of view, is at a place where the Tambo River cuts through a mountain mass extending roughly in the NW-SE direction governed by the geological structure to form a transverse valley. The Tambo Valley becomes narrowest in the vicinity of the damsite with the valley being wider upstream and downstream of the damsite.

The mountains at both banks of the damsite have relative heights of 400 to 450 m. The two banks have the same trends and slender ridges extend out toward the river channel, but the left-bank mountain body is indented at its base with gullies cutting in from both sides.

The shape of the valley at the damsite, as shown in Dwg 5.5, is that of the bottom of a boat when the boat has been cut across. The width of the riverbed portion is approximately 400 m, while above this, at a relative height of approximately 200 m, the valley width becomes approximately 1,000 m. The flow channel of the Tambo River is at the left-bank side of the riverbed and the width of the channel is approximately 140 m (as of the end of July 1984, in the dry season). The maximum depth of water according to sonic sounding equipment is approximately 8 m (as of the end of October 1984). The inclinations of the slopes at both banks are approximately 35 deg with the surfaces having relatively few undulations.

Flood plains are formed at parts of the left-bank upstream side and right-bank downstream side of the riverbed.

According to a 1/25,000-scale topographic map prepared from aerial photographs taken in 1984 the elevation of the riverbed in the vicinity of the damsite is approximately 282 m.

(3) Geology

1) Distribution and Lithology of Bedrocks

Outcrops of bedrocks are seen at this damsite at the skirts of the slopes at both banks and the vicinity of the mountaintop at the right-bank side. At Drillhole DT-2, the existence of bedrocks was confirmed between a depth of 17.5 m and the bottom of the hole at a depth of 50 m. The bedrocks confirmed in investigations up to the present listed in order from young age to old based on lithological features, as shown in Dwgs. 5.4, 5.5 and 5.6, may be classified according to the three units of alternations of sandstone and marl (Ss/Mr), sandsone (Ss), and limestone (Ls). The geological ages of these rock units, according to existing data, are Tertiary (Paleocene?) for the Ss/Mr unit, Cretaceous to Jurassic for the Ss unit, and Triassic for the Ls unit, although there is an opinion that the last unit is older than Triassic. *6)

These rock units have strikes of N60° - 70°W and dips of 35° - 45°SW, that is, they are distributed at the damsite striking roughly parallel to the dam axis and dipping to the upstream side.

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*6) According to Mr. C. Rangel (Geologist) of the Institue of Geology and Mineralogy, Peru, the age of this limestone formation is considered to be older than Triassic because of yielding of fossils in this formation.

The rock unit Ss/Mr is seen at the foots of the slopes of both banks upstream of the damsite and is composed of alternations of sandstones, marl, and shale, the thickness of each individual layer being not more than 1 to 2 m. The sandstones of this unit are reddish brown and medium- to fine-grained, and gray and medium- to fine-grained. The marl is generally gray in color and partially consists of what is thought could more aptly be called calcareous shale having distinct bedding planes. *7) The shale is gray to blackish gray in color and is non-calcareous. This unit is well-stratified and is somewhat weathered at outcrops so that each kind of rock has become slightly softened. This unit, in comparison with the others, is thought to be the most inferior in degree of consolidation and hardness even considering deterioration due to weathering.

The rock unit Ss may be observed as outcrops at the river bank on the upstream right side of the damsite vicinity, and is mostly composed of light yellowish gray to gray, very hard and dense siliceous sandstone, underlying which there are alternations of similar sandstone and hard and dense marl.

The rock unit Ls shows only slight outcropping upstream on both banks at the damsite and has also been confirmed in Drillhole DT-2. *8) It mainly consists of a gray-colored, hard, dense limestone, with partial intercalations of gray to grayish black marl or shale. The limestone has a hard, dense lithological character and solution phenomena (Karstification) are not very pronounced.

What the bedrock overlain by rock unit Ls might be has not been confirmed either by outcrops or by core drilling.

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*7) Marl or calcareous shale is distributed not only at the Tambo Puerto Prado site, but also at the Ene Paquitzapango site. Data are still too scarce, and it is difficult for a strict differentiation to be made between marl and calcareous shale, and in this report the term "marl" is comprehensively used for the moment.

2) Geological Structure

Regarding the geological structures of the basement rocks all of the rock units at the damsite and its vicinity are homoclinal and all dip toward the upstream side (35 - 45 deg), but the strikes differ slightly between the two banks. That is, whereas strikes of N60° - 70°W are indicated at the right-bank side, at the left-bank side N40°W is indicated, and what this difference is caused by is unknown at the present time.

3) Fault

It has been estimated from photogeological interpretations that a fault approximately orthogonal to the Tambo River exists in the vicinity of the damsite on the downstream side (600 to 700 m downstream of planned dam axis). This estimated fault, according to seismic prospecting, is indicated to be a relatively low-velocity zone (see Dwg. 5.5). There is little outcropping of bedrocks at this site and information concerning faults is scarce. The only fault confirmed so far is the one minor fault between depths of 37.45 and 37.65 m in Drillhole DT-2 (clay thought to be clearly due to faulting having been confirmed.)

4) Karst

This site has distributions of limestone and calcareous rocks, and so far as seen at outcrops and the core of Drillhole DT-2, extreme karst phenomena are not noticeable. However, at the present time, there is too little data available to discuss karst phenomena at this site, and nothing conclusive can be said as yet.

8*) It is microscopically examined that the name of the rock sample from DT-2 at a depth of 35.5 m is "aphanitic limestone".

5) Distrbution and Character of Overburden

The overburden at this site consists of riverbed deposits, flood plain deposits, and talus deposits.

The riverbed deposits are mainly sand-gravel at the surface, but there is a possibility that silt or clay is contained. The reason is that permeability tests at Drillholes DT-1 and DT-3 penetrating the riverbed deposits suggest the existence of silt or clay.

The flood plain deposits are composed of silt, fine-grained sand, and small gravels.

The talus deposits contain topsoil, and are composed of clay, silt, androck fragments of a great variety of sizes.

This overburden thickly covers the greater part of the damsite and vicinity. The river valley is filled thickly by riverbed and flood plain deposits, and according to the results of seismic prospecting and subsurface exploration with drillholes, riverbed deposits exceeding 40 m in thickness have been confirmed, and it has been indicated that at the deepest part it is possible for deposits of 60 to 70 m or even more to exist.

Topsoil and talus deposits cover the greater parts of the slopes at both abutments of the damsite and according to the results of seismic prospecting it has been indicated that the thickness may reach 20 m at maximum.

(4) Geotechnical Features

1) P-Wave Velocity of Ground

The P-wave velocity values (seismic primary wave velocity = Vp) obtained in seismic prospecting (refraction method) carried out at this site may be characteristically classified according to five layers. Table 5-8 shows the Vp values of the five layers for each seismic traverse at this site. According to the results of Drillholes DT-1, 2, and 3, the Vp values of riverbed sand-gravel deposits were 0.4 to 0.5 km/sec at the surface layer

Table 5-8 Vp Values (in km/sec) of Each Traverse at Tambo Puerto Prado

Seismic Traverse / Layer	ST-1	ST-2	ST-3	ST-4	ST-5	Geological Correspondence (assumed)
1st Layer	0.2 - 0.5	0.2 - 0.5	0.2 - 0.4	0.3 - 0.4	0.2 - 0.4	Topsoil, Surficial riverbed or flood plane deposits
2nd Layer	0.6 - 1.0	0.8 - 1.1	0.7 - 0.9	0.5 - 1.2	0.5 - 0.6	Talus, riverbed, and flood plane deposits and weathered bedrock
3rd Layer	0.9 - 1.3	-	-	-	0.9 - 1.0	
4th Layer	1.5 - 2.4	1.9 - 2.6	1.8 - 2.5	2.0 - 2.5	2.2 - 2.5	
5th Layer	3.1 - 3.8	3.1 - 3.4	2.9 - 3.8	3.1 - 4.0	3.3 - 3.6	Bedrocks

and 1.7 - 1.8 to 2.4 - 2.6 km/sec at deep parts, while with talus deposits 0.5 - 0.6 to 1.2 - 1.3 km/sec were indicated. Further, the Vp values of the bedrocks of limestone interbedded with marl and shale at Drillhole DT-2 were indicated to be 3.8 or 4.0 km/sec. *9)

The geophysical and geological sections along each seismic traverse are shown in Dwgs. 5.5 and 5.6, and in particular, the distribution characteristics of Vp values of the slopes at both abutments of the damsite and the riverbed are points that must be paid attention in making assessments of engineering geology.

2) Coefficient of Permeability

Permeability tests were performed at all drillholes at this site, and the results are given in Dwg. 5.6, "Geological Logs of Drillholes." The permeability test method adopted at this site and the records of the tests are indicated in Appendices 2 [7], [8] and [9].

The results of permeability tests at this site may be summarized as follows:

° There are sections of riverbed depoists where permeability coefficients of the orders of 10^{-2} cm/sec and 10^{-5} to 10^{-6} cm/sec are respectively indicated.

° Of the above locations, those indicating values of 10^{-5} to 10^{-6} cm/sec may be said to be fairly impervious. On examination of the cores drilled from those portions only sand and gravel had been recovered, but probably there were actually finer particles (silt or clay) contained, which were washed away during drilling.

° At Drillhole DT-2, shale and limestone have been confirmed as bedrocks, and the coefficients of permeability of those parts are approximately of the order of 10^{-3} cm/sec.

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*9) That "3.8 or 4.0 km/sec" is indicated as Vp for bedrocks at the same location is thought probably to be due to heterogeneity.

- ° Judged by the conditions of cores from these bedrocks, the impression received is that the abovementioned coefficients of permeability are slightly excessive, but from an engineering geology point of view the permeability is not such as to be a cause of great concern.

3) RQD

Drilling at this site passed through bedrocks only between depths of 17.5 and 50 m at Drillhole DT-2, and the RQD (Rock Quality Designation) of cores recovered from this section are shown in the geological log of Dwg. 5.6. At DT-2, shale is contained in limestone to a proportion of approximately 28 percent with parts of shale seldom being of core lengths greater than 10 cm. The RQD of the bedrocks at DT-2 averages 38.6 percent.

(5) Geological Engineering Assessment

1) Damsite

Topographically, this site corresponds to the first relatively narrow part of the valley after the Ene and Perene rivers merge to become the Tambo River and is a prospective site for a dam. Regarding the type and height of the dam, they are presently at the stage of undergoing comparison studies.

Meanwhile, the informations concerning the geology of this site is very limited as previously mentioned, and the time is still immature for making a detailed geological engineering assessment of the damsite Therefore, what was done here was to make a geological engineering assessment of the site based on the topographical and geological conditions disclosed up to this time.

- ° The river valley portion of this site is prominently filled by thick riverbed deposits. It has been confirmed at Drillhole DT-3 that this thickness is at least 40 m, while when a comprehensive judgment is made of the results of seismic prospecting and aerial photo interpretation, it is estimated that the part of maximum thickness will be 60 to 70 m or even greater.

° The existence of such a thick sand-gravel layer at the damsite means that various problems will arise when providing cofferdams at the first stage of construction. Further, when a concrete-type dam is to be considered, all riverbed deposits must be removed from the foundation of the dam. In the case of a fill-type dam, the riverbed depoits would be removed from only the impervious core portion, or otherwise, it would be absolutely necessary for a sufficiently reliable impervious zone to be made in the deposits.

° The slopes at both banks of this site do not have outcrops of bedrocks except at their skirts, and the results of seismic prospecting performed there indicate that the zone of Vp (velocity of seismic primary wave) from 1.6 to 1.9 km/sec is distributed to a depth of 20 m or possibly more. That such a zone of comparatively low velocity exists suggests that it consists of unconsolidated soft materials, and whatever the type of the dam, it should be the object of excavation and removal or fairly careful foundation treatment to serve as a foundation for the dam abutments.

° The Vp values of bedrocks at this site, with the exception of zones of comparatively low velocities, are 3.0 to 4.0 km/sec, a comparatively broad range. The larger that the value of Vp obtained by the refraction method is the greater will be physical strength, while empirically, if Vp is 3 km/sec or more, it may be said to be sound rock.

° The bedrock at this site, when seen from the aspect of physical strength, appears to possess the load-bearing capacity as the foundation for a concrete-type dam of around 150-m class height.

° The coefficients of permeability of the bedrocks at this site are shown at Drillhole DT-2 to be roughly of the order of 10^{-3} cm/sec. This value indicates the necessity for foundation treatment to seal off water as a dam foundation irrespective of the type and height of the dam.

- When a fill type is selected for the dam, since the design flood discharge at this site will be 37,200 m^3/sec at a 10,000 year return period, and a very large quantity, it will become necessary to provide spillway facilities for this on the bedrocks. Therefore, when planning spillway facilities on the bedrocks, since both slopes are thickly covered by overburden as mentioned previously, it will be necessary for thorough consideration to be given this point in design.

- There is no information concerning the conditions of groundwater distributions in the mountain bodies at both banks of the damsite. Since these mountain bodies are composed of limestone and calcareous rocks, it will be necessary to gain a thorough grasp hereafter of the condition of groundwater distribution and the permeabilities of the formations comprising the mountain bodies.

2) Reservoir Area

If a dam higher than 20 to 30 m above the riverbed were to be constructed at Tambo Puerto Prado the reservoir would back up into the basins of both the Ene and Perene rivers. As frequently stated up to this point, it is known that limestone and calcareous rocks are distributed in the two basins. According to photogeological interpretations just made, although extremely small in scale, there are a number of depressions in the topography suspected of being sinkholes in the limestone distribution area. When these areas are looked upon from the viewpoint of watertightness of the reservoir, this area has little karst landforms that are extreme, while from the standpoint of geological structure, it is not such that water from the reservoir is liable to escape to other river basins, and almost all of the tributaries flowing into the basin have surface flows even in the dry season, so that when judged comprehensively, it appears that there is little possibility of large quantities of leakage occurring from the reservoir area except for the vicinity of the damsite.

However, at the present time, data for drawing a conclusion concerning this important matter are insufficient, and it is needless to say that more detailed investigations will need to be carried out depending on developments about the project and the final selection of the reservoir high water level.

Small-scale slope failures are distributed locally in the reservoir area, and it appears there is nothing requiring special care to be exercised at the moment.

Additionally, according to interpretations by aerial photographs and LANDSAT images, as mentioned before, it is assumed that conciderably continuous faults with NW-SE and NE-SW trends intersect the reservoir area. When a high dam is planned at the Tambo Puerto Prado site, further detailed field investigations for these faults are necessary.

5.4.2 Ene Paquitzapango Site

(1) Geological Investigation Works

Subsurface explorations carried out by the JICA Survey Team at this site consistd of seismic prospecting and core drilling and the locations of these are shown in Dwg. 5.7.

The quantities of seismic prospecting done by the refraction method at this site are given in Table 5-9. The results of the prospecting are shown in Dwg. 5.8.

Table 5-9 Quantitative Features of the Seismic Prospecting at Ene Paquitzapango

Traverse	Length (m)	Geophone Stations	Shot Points	Magnetic Direction	Remarks
SE-1	480	47	11	N70°W	
SE-2	180	18	5	N70°W	
SE-3	240	24	7	N6°E	
SE-4*	170	17	14	N47°30'W	* Crossing the Ene River

Total 1,070 m 106 Stations 37 Points

The core drilling investigation made at this site is shown in Table 5-10. The data obtained from Drillhole DE-1 is summarized in the form of a geological log and annexed to Appendix A-2 [5]. The records of permeability tests and the calculation formula used to obtain permeability values are given in Appendices A-2 [7], [8] and [9].

Besides the abovementioned subsurface explorations regarding this damsite and its vicinity, geological reconnaissances were made along the Ene River by canoe referring to 1/10,000-scale topographical maps.

Table 5-10 Actual Quantity of Core-drilling and Permeability Test at Ene Paquitzapango

Drillhole Name	Location	Elevation (m)	Length (m)	Direction	Diameter of Drillhole (cm)	Permeability Test (Times)
DE-1	Damsite on the left-bank	345m */	50.0	Vertical	0m - 25.0m : ϕ = 9.27 (NC) 25m - 50m : ϕ = 7.31 (NX)	K_3 **/ : 7

Notes: */ The elevation of Drillhole DE-1 is roughly estimated by the aero-topographical map (1/25,000 in scale).

**/ The permeability test K_3 corresponds to the "Packer method" under constant water head.

(2) Topography

The Ene Paquitzapango site is located approximately 50 km upstream along the river channel from the confluence of the Ene and Perene rivers. The vicinity of this site is in the form of a V-shaped valley for a length of approximately 2 km, and the Ene River flows in the northeast direction approximately in a straight line through this gorge.

This gorge has a number of peaks about 1,000 m in elevation, and corresponds to a so-called transverse valley formed in a direction cutting perpendicularly across a ridge which extends in the NW-SE direction.

The shape of the valley at the part being considered as the damsite, as shown in Dwg. 5.8, has a left-bank slope of approximately 30 deg up to a relative height of 100 m, whereas the slope at the right bank is approximately 35 deg. At relative heights of 100 to 200 m from the riverbed the slope at the left-bank side is 50 to 55 deg, and that at the right-bank side is 40 to 45 deg. In the vicinity of the damsite, the width of the Ene River's flow channel is approximately 70 m with the maximum depth according to sonic sounding equipment approximately 16 m (as of the end of October 1984), while valley width at relative height of approximately 150 m (EL. 500 m) from the riverbed is approximately 480 m.

Beaches are not formed at the riverbed in the section of this gorge, but both upstream and downstream of the gorge the valley widths and riverbed widths are increased to two or three times the width of the gorge, and flood plains are formed at parts.

According to a 1/25,000 topographical map prepared from aerial photographs taken in 1984, the elevations of the river banks near the damsite are approximately 340 m.

(3) Geology

1) Distribution and Lithology of Bedrocks

Bedrocks crop out in the vicinity of this damsite along both river banks and at steeply inclined parts at mid-slope and higher. Furthermore, Drillhole DE-1 at the left-bank side of the riverbed at the damsite penetrated through bedrocks from the ground surface to a depth of 50 m underground. The bedrocks at this site confirmed in investigation works up to this point, in order from young to old are the six rock units of alternations of sandstone, marl, and shale (Alt-U), alternations of sandstone, marl, and shale (Alt-D), cherty marl (Mr-c), quartzose sandstone (Ss-q), shaly marl (Mr-s), and limestone (Ls). The geological ages of these rock units, according to existing data, are Alt-U and Alt-D, Tertiary (Paleocene?), Mr-c and Ss-q, Cretaceous, and Mr-s and Ls, Triassic. The bottommost rock unit Ls is correlative with the limestone unit (Ls) at the Tambo Puerto Prado site, and as previously mentioned, there is an opinion that this limestone is older than Triassic.

These rock units, as described later, from an anticline at the downstream side of the damsite, while to the upstream side and including the damsite, they are distributed with strikes roughly perpendicular to the Ene River (N30° - 60°W) and dips to the upstream side (20° - 35°SW).

The rock unit Alt-U is distributed in the vicinity of the upstream end of the gorge near the riverbed of the Ene River, and is thought to be distributed along the cliffs formed continuously and symmetrically on the slopes of both banks. In the geological reconnaissance just made, only outcrops of soft, weathered sandstone were confirmed at the left-bank side riverbed of the Ene River. In aerial reconnaissance by Cessna, this rock unit was seen as alternations of reddish beds and light yellowish-white beds. Further investigations are necessary regarding the geological conditions of this unit.

Rock unit Alt-D immediately underlies Alt-U, and is also exposed near the upstream end of the gorge at both banks of the riverbed. This unit, similarly to Alt-U, is distributed along cliffs formed continuously and symmetrically on the slopes of both banks, and the upstream side slopes (or wings) of the mountain body extending NW-SE and cut through by this gorge are probably formed by this unit. This unit is composed of alternations of reddish fine-grained sandstone with well-developed cross laminae, gray to dark gray muddy shale and marl, and at places, whitish fine-grained sandstone. The thicknesses of unit beds exceed 1 m at places, but mostly, there is high-frequency stratification as a whole with strata of thicknesses several tens of centimeters or under. The various rocks of this unit, so far as seen at outcrops, are distinctly inferior in hardness compared with the sandstone of rock unit Ss-q.

Rock unit Mr-c is distributed underlying Alt-D, and is a very hard and dense cherty calcareous rock of light gray color,and in this report is temporarily called "cherty marl".

Rock unit Ss-q and the underlying unit Mr-s were recovered as fresh cores at Drillhole DE-1. This unit Ss-q consists of a white, medium-grained quartzose sandstone only, and is massive as a whole. The shapes of individual grains of quartz can be discerned when this sandstone is examined by magnifying flass, so that it is constituted more or less by quartz grains only, and the lithological character is hard.

Rock unit Mr-s as a whole is mainly a calcareous, argillaceous, fine-grained sedimentary rock-marl but at Drillhole DE-1 *10), non-calcareous, dark gray shale, grayish white calcareous sandstone, and a gray or dark grayish, calcareous, conglomeratic mudstone were recovered. Shaly parts are somewhat exfoliative.

Of the rock units observed at the ground surface in the vicinity of this site, the bottommost unit Ls is distributed slightly downstream of the location presently contemplated for the dam axis. Bedding, although not distinct, can be seen in this limestone at outcrops, but in general, the rock is massive, presents a gray color and is hard and dense. Karstification of this limestone is not very marked so far as seen at outcrops.

2) Geological Structure

The various rock units comprising the bedrocks of this site indicate an anticlinal structure with the axis in a NW-SE direction. This anticlinal axis extends in a direction crossing more or less perpendicularly with the Ene River at around 750 m downstream from the projected dam axis. This axis coincides roughly with the lines of ridges extending in the NW-SE direction at both sides of the gorge. In short, these ridges are what geomorphologically may be called anticlinal ridges, and it is indicated that geologically older rock units exist successively deeper into the center.

As shown in Dwg. 5.7, this anticline is asymmetrical, with the northeast (downstream) side limb sloped more steeply than the southwest (upstream) side limb, and this characteristic is directly revealed in the topography o the mountain body.

Whereas the strike of ground strata measured at outcrops at the riverbed upstream of the vicinity of the damsite is N50° - 60°W at the right-bank side, it is N30° - 40°W at the left-bank side for a difference, even though slight. It is necessary for further investigations to be made to ascertain whether this is due to compound folding of ground strata or some other reason.

3) Faults

No prominent fault exists within the area of observations on outcrops of bedrocks in the vicinity of the damsite. According to photogeological interpretations, it is estimated that there are two faults with approximately similar trends at the downstream side of the beforementioned anticlinal axis. Even if these two faults were to actually exist it is thought they would not affect the project at this site very much, but further investigations will be necessary.

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*10) According to microscopic examinations, it is judged that cores at depths of 7.0 m and 41.8 m of the Drillhole DE-1 are "quartz arenite or quartzose sandstone" and "calcareous quartz arenite and limestone", respectively.

4) Karst

Calcareous rocks topped by limestone are distributed at this site, but in observations of outcrops along the Ene River, reconnaissances from the air by Cessna plane, and results of interpretations of aerial photographs, extreme karst phenomena cannot be recognized. However, sufficient data for discussing karst phenomena of this site are not available at the present time and nothing conclusive can be said as yet.

5) Distribution and Characters of Overburden

Overburden at this site and its surroundings consists of riverbed deposits, flood plain deposits, and talus deposits.

At the gorge section, riberbed deposits can be seen only slightly here and there at both banks of the river. The bottom of the river channel was investigated by seismic prospecting (seismic traverse SE-4), but details could not be obtained. However, in the vicinity of the damsite the width of the river channel is comparatively small at approximately 70 m as previously mentioned, so that quantity-wise, the deposits are not very much. To proceed further with this site it will be necessary to ascertain the distribution and nature of the sand-gravel at the riverbed by core drilling at a relatively early stage. In the vicinity of the damsite, talus deposits exist at mid-height of the slopes on both banks at parts presently covered by vegetation. Concrete data on their thicknesses are not available for now, but judging just by topographical conditions, it is thought thickness will not exceed several meters.

Outside of the gorge section, both upstream and downstream valley widths and riverbed widths become larger and the valleys are filled up with riverbed deposits and flood plain deposits. Data on the thicknesses there are not available, but estimated from the shapes of the valleys and the scales of the riberbeds, these deposits could well be more than several tens of meters thick.

The riberbed deposits at these places are mainly sand and gravel at the surface, but there should be fine-grained materials such as silt at places. The component materials of flood plain deposits are essentially the same as riberbed deposits, but fine-grained sand to silt are dominant at the surface.

Inside and outside the gorge, where outcrops of bedrocks cannot be seen at river banks and up to the middles of slopes, it may be considered that talus deposits are distributed. Thicknesses and properties of these deposits are unknown for the present.

(4) Geotechnical Features

1) P-Wave Velocity of Ground

The P-wave velocity values (seismic primary wave velocity = Vp) obtained in seismic prospecting (refraction method) carried out at this site may be characteristically classified according to five layers. Table 5-11 shows the Vp values of the five layers for each seismic traverse at this site.

Dwg. 5.7 shows the seismic traverses in seismic prospecting at this site, and as can be seen, none of the seismic traverses passes the point of Drillhole DE-1. The reason is that the topographical conditions in the vcinity of De-1 were not suitable for providing a seismic traverse. Therefore, the geological conditions to which the individual layers shown in Table 5-11 correspond are based on assumptions. What should be noted here is that Vp values of the fifth layer thought to indicate the P-wave velocity of bedrocks at this site are between 2.8 and 3.2 km/sec. These Vp values are low compared with the previously-mentioned values of bedrocks at Tambo-Puerto Prado (Vp = 3.1 - 4.0 km/sec). The reason they are low is thought to be either that the degrees of consolidation of the rocks are intrinsically lower, or that Vp was lowered by weathering action or some other secondary cause, but further investigations to discern the cause are necessary.

At Seismic Traverse SE-4, the values of Vp for the river channel portion are from 2.5 to 2.6 km/sec. It is assumed that these are compound values for riverbed deposits and bedrocks. That is, they may be considered to be Vp values in average for parts of riverbed deposits and of bedrocks.

Table 5-11 Vp (in km/sec) of Each Traverse at Ene Paquitzapango

Seismic Traverse / Layer	SE-1	SE-2	SE-3	SE-4	Geological Correspondence (assumed)
1st Layer	0.2 - 0.4	0.2 - 0.4	0.3 - 0.4	0.3	Topsoil, Surficial riverbed or flood plane deposits
2nd Layer	0.6 - 0.9	0.6 - 0.7	0.7 - 0.8	-	Talus, riverbed, and flood plane deposits and weathered bedrocks
3rd Layer	1.2 - 1.3	1.1 - 1.2	-	0.8 - 1.2	
4th Layer	1.5 - 2.0	1.9 - 2.2	2.4	2.2 - 3.2	
5th Layer	3.0	2.9	2.8 - 2.9		Bedrocks

The Vp values of overburden at this site are more or less the same as for the case of the Tambo Puerto Prado site previously described.

2) Coefficient of Permeability

Permeability tests by the packer method were carried out for the entire length of Drillhole DE-1 (length drilled; 50 m) except for the ground surface portion and the results are given in "Geological Log of Drillhole" in Dwg. 5.8. The permeability test method adopted at this site and the records of the tests are given in Appendices A-2 [7], [8] and [9].

The results of permeability tests at Drillhole DE-1 may be summarized as follows:

- The coefficients of permeability of the sections (quartzose sandstone) from the ground surface to around a depth of 10 m are of the order of 10^{-3} cm/sec.

- The coefficients of permeability of the sections (chiefly quartzose sandstone) from a depth of around 10 m to a depth of 35 m are of the order of 10^{-4} cm/sec.

- The coeffficients of permeability of the sections (chiefly alternations of shale and calcareous sandstone) from a depth of 35 m to the bottom of the hole (depth: 50 m) are of the order of 10^{-5} to 10^{-6} cm/sec.

- The above coefficients of permeability for the various depths mentioned are quite reasonable when checked against the conditions of the cores recovered.

3) RQD

Cores of quartzose sandstone from the ground surface to a depth of 32.1 m and mainly of alternations of calcareous sandstone and shale from 32.1 m to the hole bottom (depth: 50 m) were recovered at Drillhole DE-1. The RQD (Rock Quality Designation) of cores from DE-1 is given in the geologcal log in Dwg. 5.8, and when the RQDs in average of the quartzose sandstone and of the underlying alternations are obtained from these values, they are approximately 82 percent and approximately 51 percent, respectively. The RQD for all of the cores from DE-1 is approximately 72 percent. These RQD values signify that there is relatively little development of cracks as a whole.

(5) Geological Engineering Assessment

1) Damsite

This site, as repeatedly mentioned in this report, is located at a gorge where an anticlinal ridge has been dissected in the form of a transverse valley. Dams of concrete type of various heights are being considered at present. To make a geological engineering assessment of this site based on the non-too-abundant topographical and geological information obtained so far, it would be as follows:

° The gorge of Paquitzapango has a length of approximately 2 km through which the Ene River flows down in a more or less straight line, and at present the damsite is located near the one-third point from the upstream end of the gorge. Near the one-third point from the downstream end an anticlinal axis crosses the river channel in a roughly perpendicular direction.

° The geologically oldest rock at this site, a limestone formation (Ls unit) is distributed at the nuclear portion of this anticline. With this anticline as the boundary it appears that the downstream side has geological conditions more complex than the upstream side. Consequently, if the dam axis is to be selected based only on geological conditions, it may be said that upstream of this anticline would be more desirable.

° The dam axis is being considered at present at about 750 m upstream from this anticline, where quartzose sandstone is distributed at the riverbed, and this is thought to be reasonable from a geological standpoint. However, it cannot be said definitely whether this axis location is geologically the best at the moment due to the scarcity of data for making a judgment.

- The geological profile along the planned dam axis is shown in Dwg. 5.8 (Section A-A), and this drawing gives an outline of the geological structure of the bedrocks. Even considering that accuracies of the elevations of rock unit boundaries are not very good, it is worthy of note that hte rock unit Alt-D, and further, overlying it, Alt-U are distributed at mid-heights of slopes and higher at both sides of the river.

- The reason attention should be paid is that the rocks constituting the Alt-D unit apparently have physical properties that are inferior to those of underlying rock units, Mr-c, Ss-q, and Ls. It is possible that this matter will govern when making a final decision on the height of the dam at this site.

- A concrete type dam is considered at this site because the width of the riverbed portion and the width of the valley are small in comparison with the design flood discharge (28,400 m^3/sec). Since the slopes at both sides within the gorge have little relief on the whole it appears that there is no site where an arch type dam can be simply selected based only on topographical conditions.

- The condition of riverbed sand-gravel distribution in the vicinity of the damsite is unknown at present. Judging from the topographical conditions in the vicinity of the riverbed and the exposure conditions of bedrock, it is thought exploration by core drilling is the best way to investigate the thickness of riverbed sand-gravel at the damsite.

- Regarding permeability of the bedrocks there is nothing else but permeability test data from DE-1. Hereafter, it will be absolutely necessary for investigations to be made regarding the permeability of rock unit Ls limestone at the riverbed and to obtain data on the distribution of groundwater and the permeabilities of the two abutments.

2) Reservoir Area

Assuming that a dam of 150-m height class is built at the gorge of Paquitzapango, the backwater of the reservoir would reach to a point somewhat upstream of the confluence of the Apurimac and Mantaro rivers. The investigations regarding topography and geology made up to the present cannot be said to have been adequate, but acording to them, topographical and geological conditions where large amounts of leakage would occur from the abovementioned reservoir area to other river basins have not been found. However, since calcareous rocks are distributed inside the reservoir area, it will be necessary to upgrade the accuracies of future investigations in order to assure watertightness of the reservoir.

The surface portions of the ridges extending in the NW-SE direction at both sides of the gorge where the damsite is located may possibly be composed of Tertiary formations of comparatively poor degrees of consolidation. In case of planning a dam exceeding a height of 100 m at Paquitzapango it will first be needed to assure the watertightnesses of the ridges. Consequently, it will be necessary for investigations to be carried out to grasp the geological and hydrogeological properties of the ridges.

Although of small sizes, numerous slope failures have been found in the reservoir area, especially the upstream part, as a result of photogeological interpretations. However, it is thought none of these will require special attention at the moment.

5.4.3 Ene Cutivireni Site

(1) Topography and Geology

The Ene Cutivireni site is located approximately 60 km upstream from the Ene Paquitzapango site along the Ene River channel, approximately 2 km downstream of the hamlet of Mision at the midstream stretch of the Ene River. This site, according to a topographical map (1/25,000 scale) made by aerial photogrammetry has a river water surface at an elevation of about 385 m, and can be a candidate site for a dam only when a dam with reservoir high water level at about EL. 385 m or under is planned downstream.

Regarding this site, in addition to interpretations of aerial photographs made by the JICA Survey Team, aerial reconnaissances were made by Cessna plane toward the end of July 1984, while also a brief reconnaissance along the river channel by canoes was carried out at the end of June, 1985.

This site is at a bent of the Ene River where it changes its course from northeast to north-northwest. Upstream of this site, the Quemperi and Cutivireni rivers merge with the Ene River and a broad river beach is developed. A river beach of approximately 3 km in width is developed at the downstream side also.

The width of the river at the planned damsite is approximately 200 m, with the mountain bodies at both banks being of relative heights of 100 to 150 m from the riverbed, and a gently-sloped hilly landform is presented as a whole.

The damsite, according to existing geological data, LANDSAT imagery analyses, photogeological interpretations, and observations from canoes may possibly be composed of the Tertiary Ipururo Formation. This Ipururo Formation is said to consist of alternations of soft mudstone and sandstone, and the results of interpretations of information obtained from the air so far supports this view.

It is estimated that the strike of this formation is N30° - 50°W and the dip approximately 10°SW.

A fault trending NNE-SSW is estimated to exist approximately 1 km upstream of the damsite, and it is imagined that this fault has had an influence on the shape of the Ene River channel.

The riverbed deposits at the damsite and its vicinity form a broad river beach and appear to be of considerable thickness.

(2) Geological Engineering Assessment

A proper geologcal engineering assessment of this site cannot be made since too little geological investigations have been carried out. However, according to the topographical conditions revealed so far and the geological conditions that can be estimated, it is certain that this is not a location which is very advantageous as a site for a dam, and that even if a dam were to be built, it cannot be made a very high one.

5.4.4 Ene Sumabeni Site

(1) Topography and Geology

The Ene Sumabeni site is located approximately 50 km upstream along the Ene River from the Ene Cutivireni site, or approximately 15 km downstream from the confluence of the Apurimac and Mantaro rivers. According to a topographical map (scale: 1/25,000) by aerial photogrammetry the elevation of the water surface at the riverbed is approximately 440 m, and this would be a candidate site for a dam in case a dam of high water level approximately 440 m or lower is planned downstream.

The JICA Survey Team carried out an aerial reconnaissance by Cessna plane of this site toward the end of July 1984 in addition to LANDSAT imagery analyses and aerial photograph interpretations. Further, a brief reconnaissance along the Ene River by canoes was done at the end of June, 1985.

This site is at a river bend where the Ene River which had been flowing north-northwest changes its course to the west and again changes to the north-northeast. The riverbed at its narrowest part has a width of approximately 500 m. At the present time, it is planned for the dam axis to be at this narrowest part of the riverbed, where at the left-bank side a ridge having a comparatively steep slope extends out toward the riverbed, while at the right-bank side in general there is a broad, flat area of relative height from the riverbed plane of approximately 100 m spread out (width on extension of dam axis approximately 1 km) lying between the river and a mountain body having a comparatively steep slope.

There is a possibility that the bedrocks at the damsite are composed of the Paleozoic Ambo Group according to existing geological data, and the results of LANDSAT imagery analyses, aerial photograph interpretations just made and observations from canoes. The Ambo Group is said to consist of sedimentary rocks which are mainly shale and sandstone. These strata, according to the observations from canoes, are estimated to strike N0° - 30°E or W and dip 10° - 30°W.

The area including this site is located between a Tertiary sedimentary basin existing at the northwest side and a Paleozoic elevated block at the southeast side, and there are faults of NNW-SSE, NNE-SSW, and NE-SW systems developed in concentrated form.

Further, according to photogeological interpretations, there are many slope failures or topographical features with traces of slope failures found at this site.

Riverbed sand-gravel has filled up the broad river valley and the thickness of the deposit appears to be considerable.

(2) Geological Engineering Assessment

Similarly to the case of the Ene-Cutivireni site, the time is still immature for making a geological engineering assessment of this site.

Nevertheless, as for a damsite, it can be said that the general topography and geology of the Sumabeni site are more suitable than that of the Cutivireni site.

Of the topographical and geological conditions revealed so far, it will be necessary for special attention to be paid to the following:

- In case of planning a dam exceeding 100 m in height from the present riverbed plane, a thorough field investigation should be made and the topographical conditions of the mountain bodies at both sides of the river studied prior to selecting the dam axis.

- Investigations of slope failures or landslides in the vicinity of the damsite should be carried out and the influences on the dam or its appurtenant facilities studied.

5.5 Construction Materials

In the Master Plan for the Ene River Hydroelectric Power Development Project, a concrete or fill-type dam is contemplated for the Tambo Puerto Prado site and a concrete-type dam for the Ene Paquitzapango site. As for the Cutivireni and Sumabeni sites, fill-type dams are being considered. The dam types for the various sites may be changed depending on future developments concerning the plans. Therefore, the field conditions of all construction materials will be explained based on the geological conditions ascertained so far regarding mainly the area along the Ene River.

° Concrete Aggregates

Beaches of riverbed deposits and flood plains may be seen at the Ene River and other major streams in the area. These riverbed deposits are all composed of gravels of hard, dense rocks, sand of various grain sizes, and silt at their surfaces. These riverbed deposits may be used as concrete aggregates both quantitatively and qualitatively.

The investigations to be made hereafter concerning concrete aggregates will principally consist of basic laboratory tests performed in step with the progress at each individual site, and studies of where and how economically the aggregate materials are to be collected. Furthermore, it will be necessary for alkali reactivity tests to be carried out at a relatively early stage.

° Rock Materials

Rock materials for fill-type dams are generally required to be fresh, hard rock of high specific gravity, and moreover, massive character. At the upstream part of the Tambo River and in the Ene River Basin it is thought that the Mesozoic or Paleozoic limestone and sandstone are generally the most suitable as rocks having such lithological characters, while further, calcareous sedimentary rocks of massive character may also be included.

The rock units at Tambo Puerto Prado that would be the objects of investigations for rock materials are Ls and Ss, while further, judging by the lithological characters seen at outcrops, Ss/Mr may also be considered.

Rock units at Ene-Paquitzapango that will be sources of rock materials are Ls, Ss-q, and Mr-c. However, so far as seen as at outcrops, they are more weathered than rocks at Tambo Puerto Prado, while the conditions from the standpoint of lithological characters are thought to be slightly inferior, and care will be needed.

Regarding the two sites of Cutivireni and Sumabeni, there is no information about rock units, but when the two sites are compared, it appears that good-quality rock materials are not available in the vicinity of Cutivireni.

° Filter Materials

Filter materials for fill-type dams will be sufficiently available both quantitatively and qualitatively from the riverbed deposits in the vicinities of all of the sites.

° Impermeable Materials

In general, a material which is impermeable, has high shear resistance, and can be easily consolidated during construction is suitable as the impermeable material for a fill-type dam. In this project area, fine-grained deposits (silt or clay) from among talus deposits, weathered bedrocks, and flood plain deposits will be objects of investigation.

Judging from the results of reconnaissances in the project area it is thought there are locations which could be objects of investigations for impermeable materials within radii of 5 to 6 km at all of the sites.

5.6 Probability Analysis on Seismic Acceleration

5.6.1 Seismicity Data

Seismicity data used in this study are those compiled by NOAA (National Oceanic and Atmospheric Administration Environmental Data Service). A magnetic tape offered by ONERN in Lima contains the data for a wide region covering from 30°W to 85°W and from 60°S to 15°N during the period from 1868 to 1981. Before 1925, however, the data are not available for this study mainly due to lack of earthquake magnitude.

Meanwhile, the concerned project sites are located around 11° - 12°S and 74°W, as shown in Table 5-12. General aspects on seismicity around the project sites can be seen from Figs. 1 - 9, in Appendix A-5 in which locations of the sites and epicenters of the seismic data from 1925 to 1981 are plotted in accordance with their magnitude and focal-depth ranks.

For the sake of simplicity, three project sites; that is, Tambo Puerto Prado, Ene Paquitzapango and Ene Sumabeni, are refered to as site A, B and C respectively, and symbols A, B and C will be used to indicate each site in this description. Tables A-1, B-1 and C-1 in Appendix A-5 show distribution of magnitude and epicentral distance of the earthquakes available for this study. As for the earthquakes listed in these tables, numbers of the earthquakes occured in a year during the period 1925 to 1981 are shown in Tables A-2, B-2 and C-2 in Appendix A-5, together with accumulative numbers from 1925.

5.6.2 Attenuation Models

Of previously proposed attenuation models which express peak acceleration, A (gal), in terms of earthquake magnitude, M, and hypocentral distance, R (km), or epicentral distance, D (km), four models shown below are used in this study.

$$\text{Log } A = 3.090 + 0.347M - 2 \log (R+25) \quad (1)$$

proposed by C. Oliveira[1].

$$\text{Log } A = 2.674 + 0.278M - 1.301 \log (R+25) \quad (2)$$

proposed by R. K. McGuire[2].

$$\text{Log } A = 2.041 + 0.347M - 1.6 \log D \quad (3)$$

proposed by L. Esteva and E. Rosenblueth[3].

$$\text{Log } A = 2.308 + 0.411M - 1.637 \log (R+30) \quad (4)$$

proposed by T. Katayama[4].

References:

1) Oliveira, C.; Seismic Risk Analysis, EERC 74-1, Earthquake Engineering Research Center, University of California, Berkeley (1974), 1-102.

2) McGuire, R. K.: Seismic Structural Response Risk Analysis incorporating Peak Response Regressions on Earthquake Magnitude and Distance. Mass. Inst. Technol. Dep. Civ. Eng., R74-51 (1974)

3) Esteva, L. and Rosenblueth, E.: Espectros de Temblores A Distancias Moderadas y Grandes, Proc. Chilean Conference on Seismology and Earthquake Engineering, Vol. 1, University of Chile (1963).

4) Katayama, T.; Fundamentals of Probabilistic Evaluation of Seismic Activity and Seismic Risk (in Japanese), SEISAN-KENKYU (Monthly Journal of Institute of Industrial Science, University of Tokyo), 27-5 (1975), 1-11.

5.6.3 Statistical Analysis of Maximum Accelerations

The seismicity data are available for successive 56 years from 1925 to 1981 for each site. Thus, a probability model based on the "Theory of Extreme Values" can be established by taking an equal time interval to be one year.

Although a probability function of the maximum acceleration expected at a dam site is not known, it is reasonable to suppose that the function should be associated with the third type asymptotic distribution defined by

$$P(x) = \exp\ [-[(w-k)/(w-u)]^k]$$

where w is an upper limit of a variable, k is a shape parameter, u is a characteristic value, and x is a random variable taken as logarithm of the maximum acceleration during a year-long interval, expressed as

$$x = \log A_{max}$$

In Tables A-3, B-3 and C-3 in Appendix A-[5], maximum accelerations during a year from 1925 to 1981 are shown for every attenuation model described previously. The maximum values are plotted in Figs. A-1 -5, B-1 -5, and C-1 -5 in Appendix A-[5]. Plotting position of each maximum value was calculated by

$$p(m) = (N-m+1)/(N+1)$$

where N (=56) is the total number of the time interval and m is the order of the value from the largest one. In these figures, regresion curves estimated for the third asymptotic distribution function are also shown by solid lines, from which the maximum acceleration for any return period can be evaluated. Table 5-13, 5-14 and 5-15 show the maximum acclerations expected at each site for different three return periods of 50, 100 and 200 years.

Table 5-12 Location of Project Sites

	S	W
A: Tambo Puerto Prado (Tambo-10)	11°09'10"	74°14'21"
B: Ene Paquitzapango (Ene-40)	11°31'04"	74°04'30"
C: Ene Sumabeni (Ene-10)	12°09'50"	74°04'13"

Table 5-13 Maximum Accelerations for Three Return Periods (gal)

Model (Eq.No.)	Proposer(s)	Return Period, Tr (year)		
		50	100	200
(1)	C. Oliveira	33.5	53.4	82.7
(2)	R. K. McGuire	94.9	133.3	185.4
(3)	L. Esteva & E. Rosenbiueth	30.8	51.8	86.4
(4)	T. Katayama	59.6	92.4	142.6

Table 5-14 Maximum Accelerations for Three Return Periods (gal)

Model (Eq.No.)	Proposer(s)	Return Period, Tr (year)		
		50	100	200
(1)	C. Oliveira	22.7	31.0	40.9
(2)	R. K. McGuire	74.5	94.4	117.2
(3)	L. Esteva & E. Rosenbiueth	22.3	32.3	45.4
(4)	T. Katayama	44.9	61.7	82.8

Table 5-15 Maximum Accelerations for Three Return Periods (gal)

Model (Eq.No.)	Proposer(s)	Return Period, Tr (year)		
		50	100	200
(1)	C. Oliveira	32.1	56.4	98.8
(2)	R. K. McGuire	87.2	124.4	177.1
(3)	L. Esteva & E. Rosenbiueth	46.6	87.6	164.4
(4)	T. Katayama	47.2	69.6	101.7

5.7 Conclusions

(1) Tambo Puerto Prado Site

1) What is most noteworthy about this site from topographical and geological viewpoints is that there are riverbed deposits confirmed to be not less than 40 m in thickness (and estimated to be 60 to 70 m or even more at the thickest parts).

2) The foundation rocks at the damsite comprise limestone, sandstone, shale, and marl of the Mesozoic Era (with a part possibly of the Paleozoic Era), and these rocks themselves are thought ot possess strengths at which bearing capacities for a concrete dam of a class one hundred and several tens of meters in height can be expected. However, it was indicated in permeability tests performed at Drillhole DT-2 at the left-bank side of the riverbed that coefficients of permeability of these bedrocks were of the order of 10^{-3} cm/sec. So far as observations made of cores from that location are concerned, the rocks are geotechnically groutable, but it will be necessary for thorough care to be exercised hereafter regarding permeability of the dam foundation.

3) It has been found that materials with Vp values 2 km/sec or under are distributed at both abutments of the damsite to depths of 15 to 20 m, and deepper at places. This indicates that soft materials (overburden or strongly weathered bedrocks) are distributed at the slopes on both sides, and this will need further thorough investigation.

4) The conditions of groundwater distributions inside the mountains at both banks are presently unknown. Since these mountains are partially composed of limestone and calcareous rocks, it will be necessary hereafter for the groundwater distribution conditions in the mountains and the permeabilities of the rocks making up the mountains to be investigated.

5) Seen from an engineering geology point of view, it may be said as a conclusion that this site would be suitable for a dam if the problem of the method of handling the thick sand-gravel layer at the riverbed can be resolved.

6) In case a high dam (e.g., its height: more than 50 m above the riverbed) is planned, from a view point of reservoir geology it will be necessary for further investigations as follows:

   One is detailed geological-hydrogeological investigations for mountain ranges on both banks of the damsite.

   Another is field geological investigations for two faults intersecting the reservoir area with NW-SE and NE-SW trends, which are assumed by interpretations of aerial photographs and LANDSAT images.

(2) Ene Paquitzapango Site

1) The foundation rocks of the damsite at this location consist of limestone, sandstone, shale, and marl of the Mesozoic Era (partially Paleozoic Era?) from the riverbed portion to mid-heights of the slopes at both sides of the river, and these rocks themselves probably possess strengths providing bearing capacities for a concrete dam of a class one hundred and several tens of meters in height. However, Tertiary sedimentary rocks are distributed above mid-slope on both sides and the physical properties of these rocks are inferior to those of underlying bedrocks.

2) It is thought riverbed deposits are distributed at the flow channel of the river, but the thicknesses are unknown. It will be necessary to ascertain (for example, by core drilling) at as early an opportunity as possible what the thicknesses of deposits are at the damsite and the upstream and downstream sides of the damsite.

3) The mountain bodies at both banks of the damsite are comprised by anticlinal ridges with the nuclear portions of the ridges consisting of limestone of Mesozoic or Paleozoic geological age, while the ground surface portion consists of Tertiary alternations of sandstone, shale, and marl. Whether the two ridges are sufficiently watertight will be a problem when a dam of a class one hundred and several tens of meters in height is to be considered. Therefore,it will be absolutely necessary hereafter

to gain a grasp of the distribution conditions of groundwater and the permeabilities there.

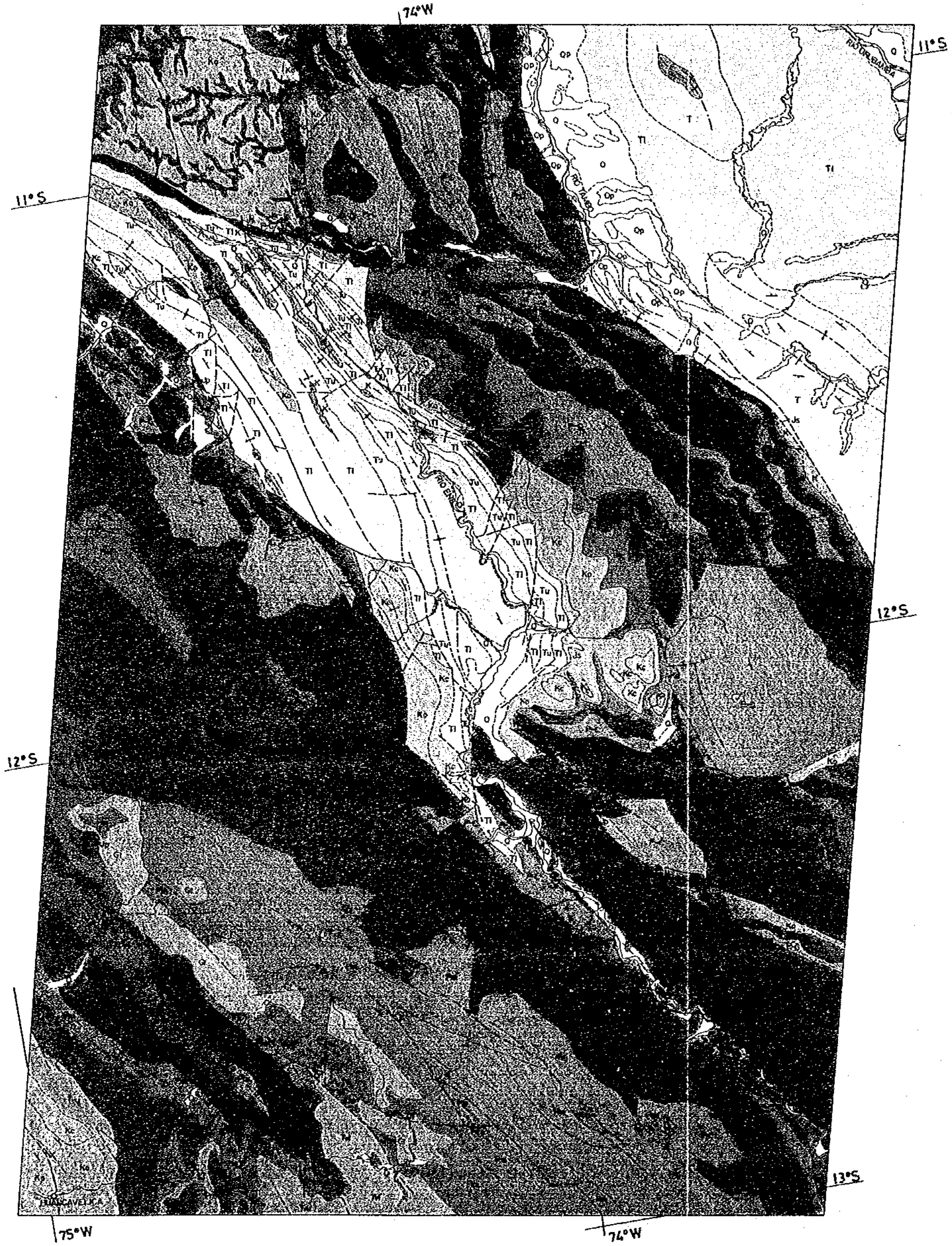
4) From an engineering geology point of view, in order to obtain assurance of economically constructing a concrete-type dam of a class one hundred and several tens of meters in height, it may be concluded that it will first be necessary to investigate the permeability of the limestone at the riverbed, and the permeabilities and physical strengths of the Tertiary rock units above mid-heights of the slopes on both sides.

(3) Ene Cutivireni Site

Data for making a geological engineering assessment of this site are insufficient, but it is clear at least that it will be impossible for a dam higher than 100 m to be constructed, while it cannot be thought the site has generally favorable topographical and geological conditions.

(4) Ene Sumabeni Site

Data for making a geological engineering assessment of this site are too insufficient just as at the beforementioned Cutivireni site. As for a dam site, however, it is seemed that the topographical and geological conditions of this site, are more suitable than that of the Cutivireni site. Judging by the topographical and geological information obtained concerning this site so far it will be absolutely necessary for further field surveys to be carried out including examinations of minute details of the topography at the site, and investigations of slope failures to be made.



LEGEND

Quaternary	Q : Alluvium Qp : Pagorene fm	
Tertiary	Tvu : Senca fm Tvl : Huanta gp	Gt : granite
	Ti : Ipururo fm Tu. Tl : Huayabamba gp	
Cretaceous	Kc : Chonta fm Ko : Oriente gp	
Jurassic	Js : Sarayaquill fm	
Jurassic~ Triassic	Jp : Pucara—Ene fm	
Permian	Pm : Mits gp	
Permian~ Carboniferous	P—C : Tarma—Copacabara gp	
Carboniferous	Ca : Ambo gp	
Devonian~ Ordovician	O—D : Exelsior gp	Gp : granite
Pre—Cambrian	Pr—C : metamorphics	

Stratigraphical boundary — Anticline

Fault — Syncline

Notes This map is compiled on the basis of data as follows:

1. MAPA GEOLOGICO DEL PERU (Scale: 1/1,000,000), INGM., 1975.
2. Geological Map of Petro-Peru (Scale: 1/500,000), 1968.
3. LANDSAT Images Processed of Digital Mosaic, (Scales: 1/1,000,000, 1/500,000, and 1/250,000), JICA MISSION, 1985.

0 10 20 30 40 50 km

ENE RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL PLAN OF ENE RIVER BASIN

DWG. 5.1

Notes

1) : This map is compiled on the basis of data as follows:

1. Geological Map of Petro-Peru (scale: 1/500,000), 19(

2. Geological Map of Electro-Peru (scale: 1/100,000), 19-

3. Results of aero-photo interpretations (1984) and geo

reconnaissances (1984, 1985) by JICA Mission

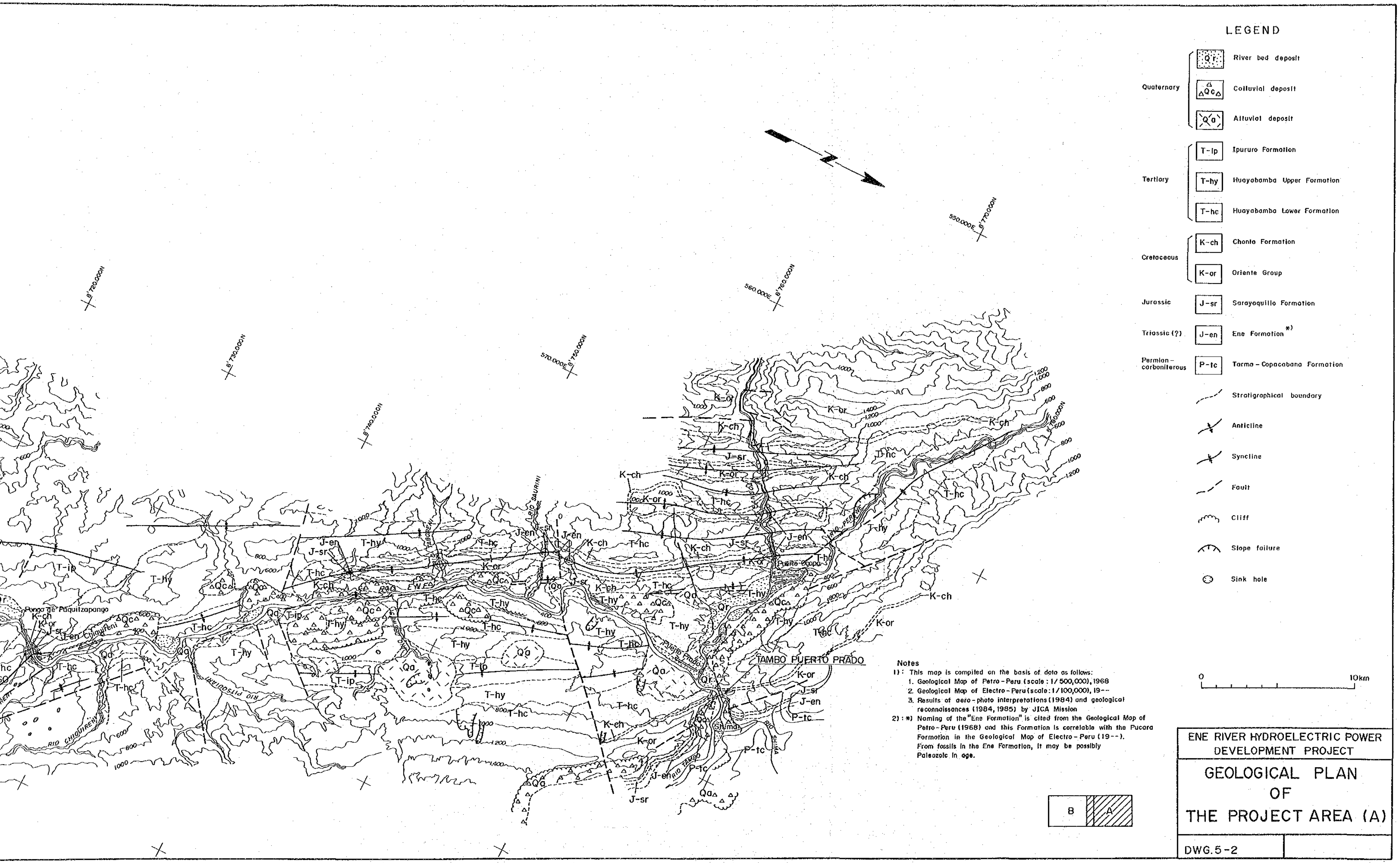
2) : *) Naming of the "Ene Formation" is cited from the Geol(

Petro-Peru (1968) and this Formation is correlable w

Formation in the Geological Map of Electro-Peru (

From fossils in the Ene Formation, it may be possibly

Paleozoic in age.



Notes

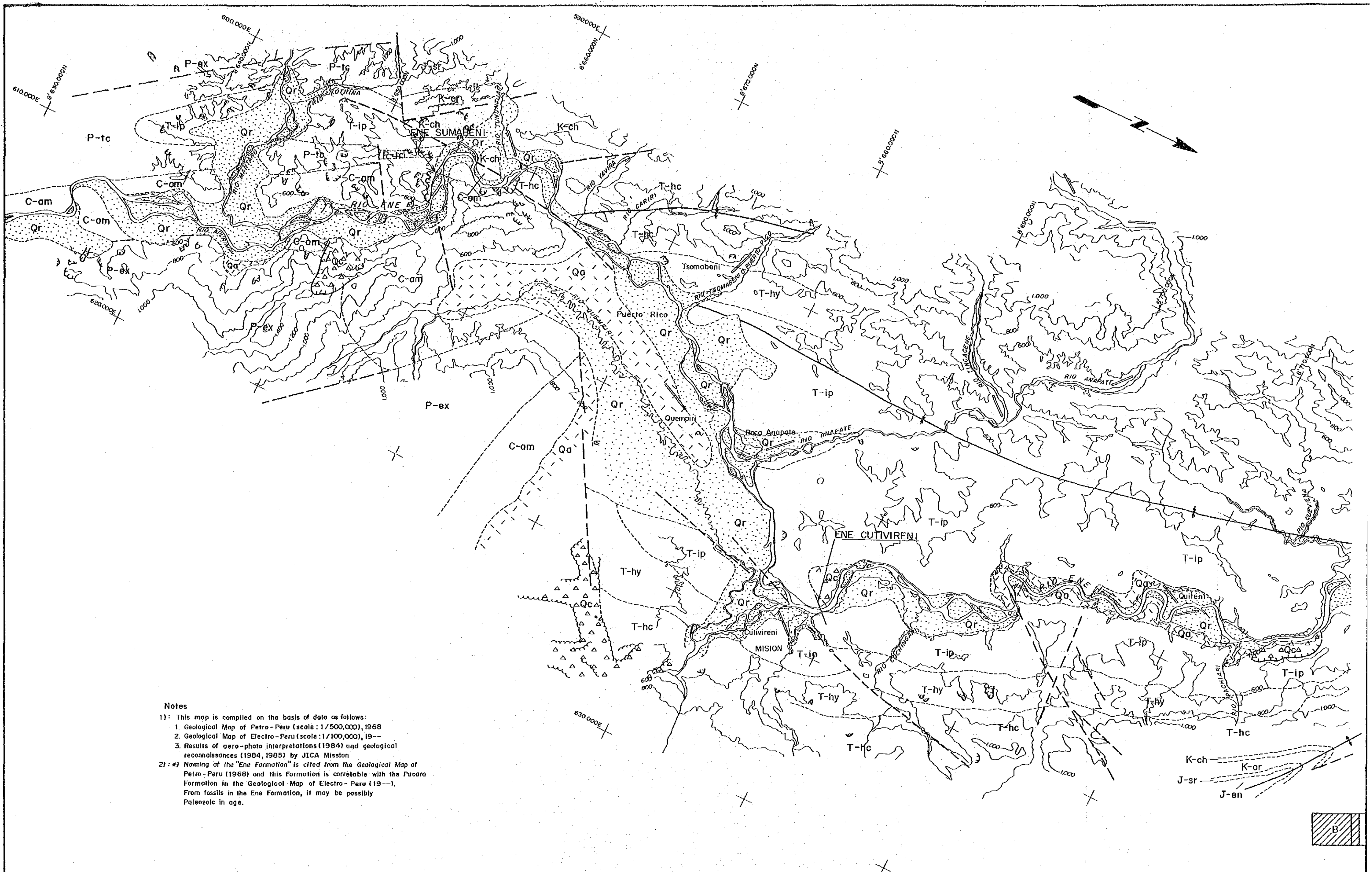
1): This map is compiled on the basis of data as follows:
1. Geological Map of Petro - Peru (scale : 1/ 500,000), 1968
2. Geological Map of Electro - Peru (scale : 1/100,000), 19--
3. Results of aero - photo interpretations (1984) and geological reconnaissances (1984, 1985) by JICA Mission

2): *) Naming of the "Ene Formation" is cited from the Geological Map of Petro - Peru (1968) and this Formation is correlable with the Pucara Formation in the Geological Map of Electro - Peru (19--). From fossils in the Ene Formation, it may be possibly Paleozoic in age.

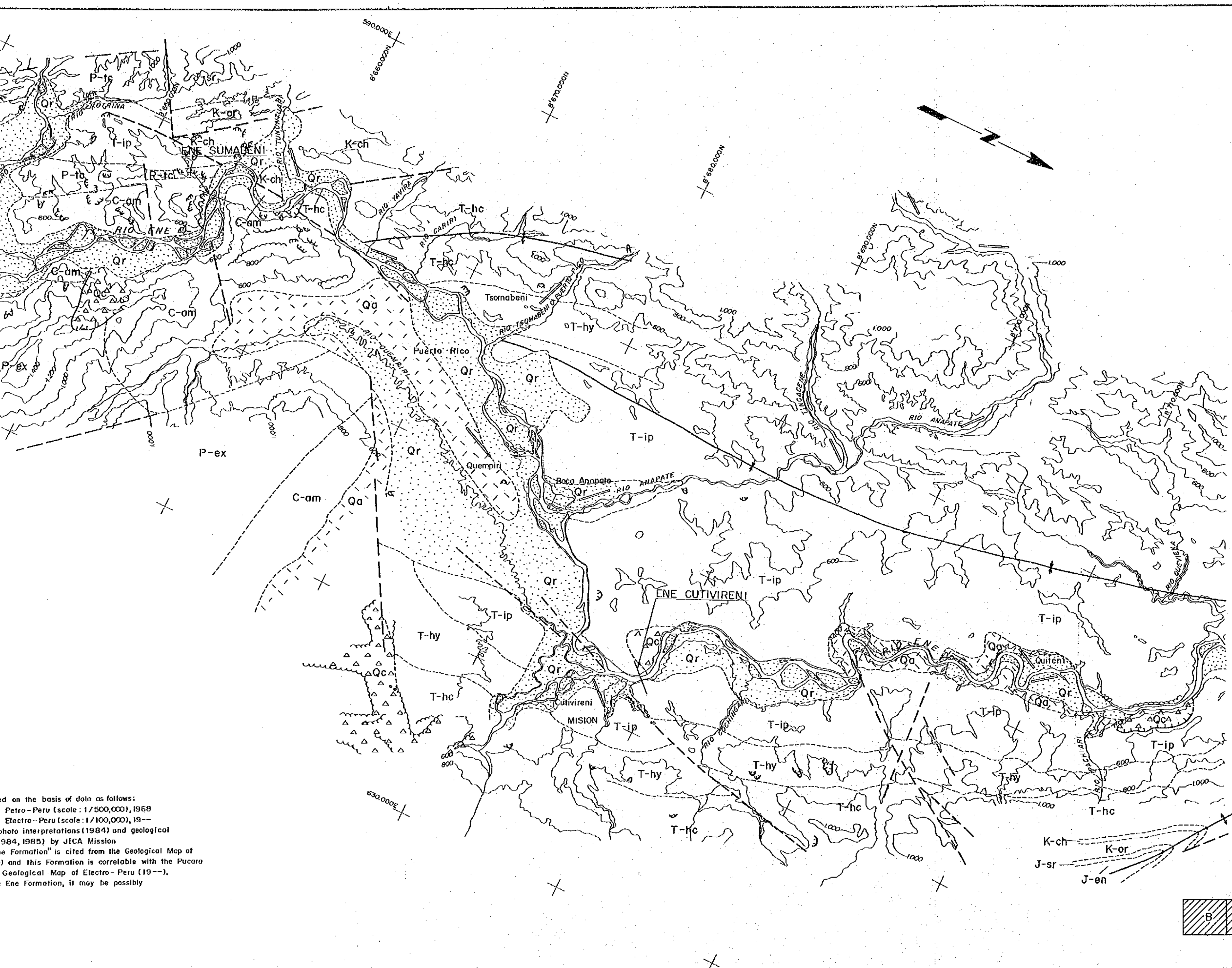
ENE RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL PLAN OF THE PROJECT AREA (A)

DWG. 5 - 2



P-ex
P-tc
K-or
ENE SUMABENI
T-ip
Qr
K-ch
C-am
T-hc
RIO ENE
RIO YAVIRA
RIO CARIRI
Tsomabeni
T-hy
Qa
Qc
Puerto Rico
P-ex
Quempiri
Boca Anapate
RIO ANAPATE
ENE CUTIVIRENI
Cutivireni
MISION
Quiteni
K-ch
K-or
J-sr
J-en
Notes
1): This map is compiled on the basis of data as follows:
1. Geological Map of Petro-Peru (scale: 1/500,000), 1968
2. Geological Map of Electro-Peru (scale: 1/100,000), 19--
3. Results of aero-photo interpretations (1984) and geological reconnaissances (1984, 1985) by JICA Mission
2): *) Naming of the "Ene Formation" is cited from the Geological Map of Petro-Peru (1968) and this Formation is correlable with the Pucara Formation in the Geological Map of Electro-Peru (19--).
From fossils in the Ene Formation, it may be possibly Paleozoic in age.



LEGEND

Quaternary	Qr	River bed deposit
	Qc	Colluvial deposit
	Qa	Alluvial deposit
Tertiary	T-ip	Ipururo Formation
	T-hy	Huayabamba Upper Formation
	T-hc	Huayabamba Lower Formation
Cretaceous	K-ch	Chonta Formation
	K-or	Oriente Group
Jurassic	J-sr	Sarayaquillo Formation
Triassic (?)	J-en	Ene Formation*)
Permian-carboniferous	P-tc	Tarma - Copacabana Formation
Carboniferous	C-am	Ambo Group
Silurian	P-ex	Excelsior Formation

Stratigraphical boundary

Anticline

Syncline

Fault

Cliff

Slope failure

Sink hole

0 10km

ed on the basis of data as follows:
Petro-Peru (scale: 1/500,000), 1968
Electro-Peru (scale: 1/100,000), 19--
photo interpretations (1984) and geological
984, 1985) by JICA Mission
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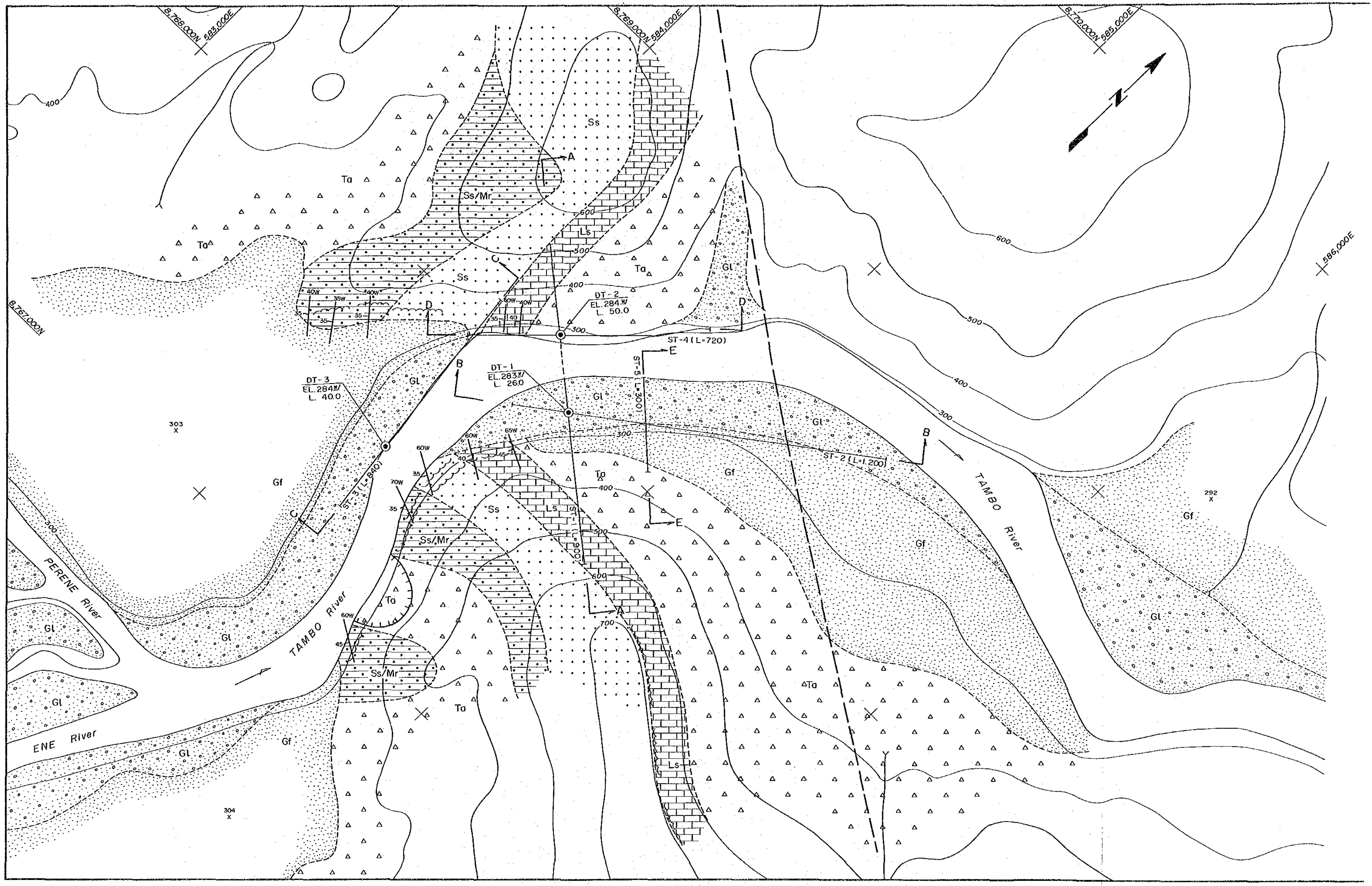
) and this Formation is correlable with the Pucara
Geological Map of Electro-Peru (19--).
Ene Formation, it may be possibly

B A

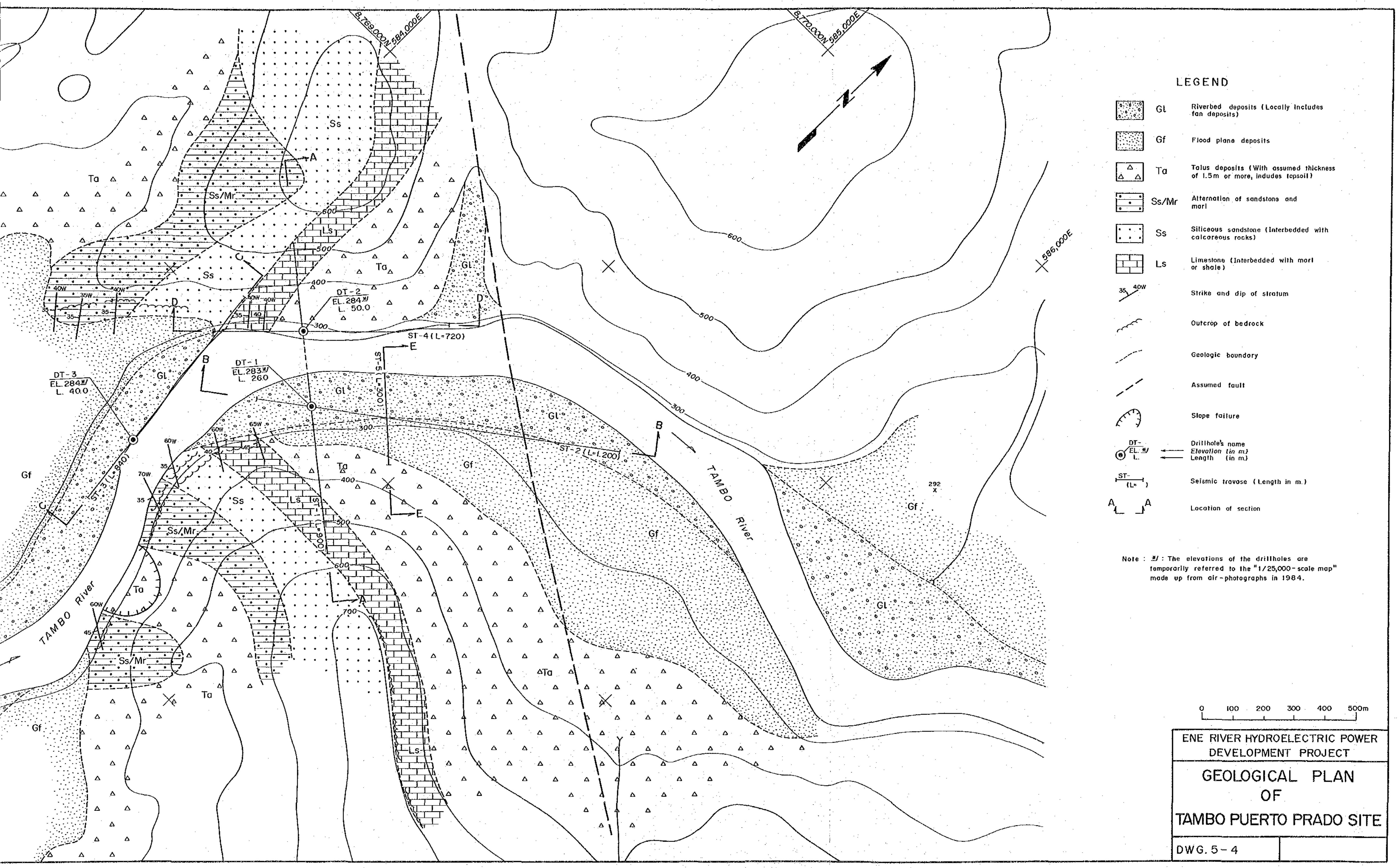
ENE RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

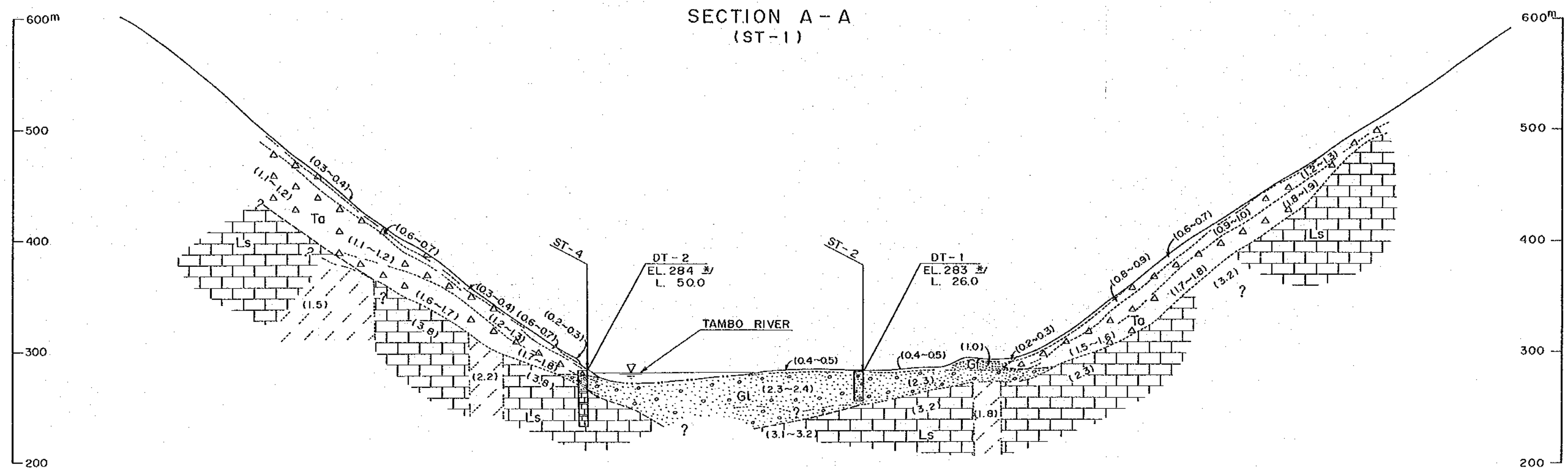
GEOLOGICAL PLAN OF THE PROJECT AREA (B)

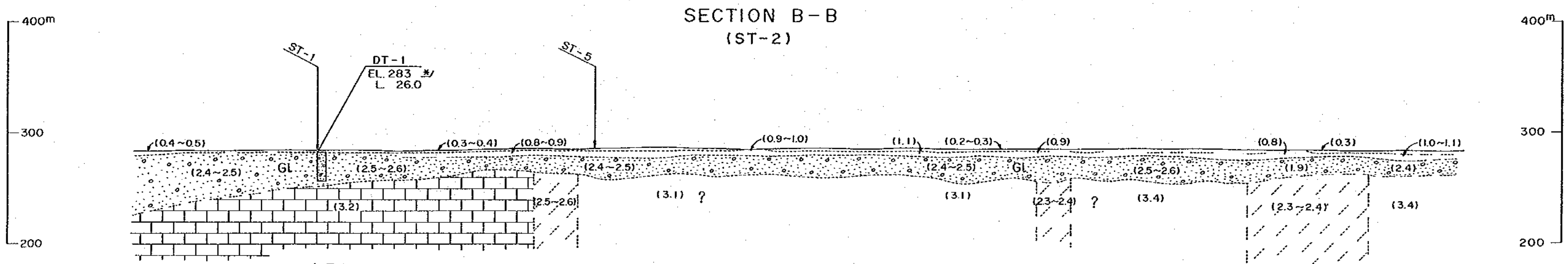
DWG. 5-3



8,766,000N 583,000E
8,769,000N 584,000E
8,770,000N 585,000E
586,000E
8,767,000N
N
Ta
Ss/Mr
Ss
Ls
Gl
Gf
DT-2 EL.284 L. 50.0
DT-1 EL.283 L. 26.0
DT-3 EL.284 L. 40.0
ST-4 (L=720)
ST-5 (L=300)
ST-2 (L=1,200)
ST-3 (L=840)
ST-1 (L=900)
TAMBO River
PERENE River
ENE River
400
500
600
700
300
303
304
292


LEGEND
Gl Riverbed deposits (Locally includes fan deposits)
Gf Flood plane deposits
Ta Talus deposits (With assumed thickness of 1.5m or more, includes topsoil)
Ss/Mr Alternation of sandstone and marl
Ss Siliceous sandstone (Interbedded with calcareous rocks)
Ls Limestone (Interbedded with marl or shale)
Strike and dip of stratum
Outcrop of bedrock
Geologic boundary
Assumed fault
Slope failure
Drillhole's name
Elevation (in m)
Length (in m)
Seismic travase (Length in m.)
Location of section
Note : ※/ : The elevations of the drillholes are temporarily referred to the "1/25,000-scale map" made up from air-photographs in 1984.
0 100 200 300 400 500m
8,769,000N 584,000E
8,770,000N 585,000E
586,000E
DT-1 EL.283※/ L. 26.0
DT-2 EL.284※/ L. 50.0
DT-3 EL.284※/ L. 40.0
ST-2 (L=1,200)
ST-3 (L=840)
ST-4 (L=720)
ST-5 (L=300)
ST-1 (L=900)
TAMBO River
ENE RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT
GEOLOGICAL PLAN OF TAMBO PUERTO PRADO SITE
DWG. 5-4





LEGEND

Gl	Riverbed deposits (Silt, sand, glavel)
Gf	Flood plane deposits (Silt, sand, glavel)
Ta	Talus deposits (Silt, clay, rock fragments)
Ls	Limestone (Interbedded with marl or shale)
	Geological boundary
	Bottom of river water (By echo sounding device, on 1st, Nov. 1984)
(2.4~2.5) (3.1)	Seismic primary wave velocity (in km/sec) and its boundary
(1.8)	Relatively low velocity zone (in km/sec)
DT- EL. L.	Drillhole's name, Elevation (in m.), Length (in m.)
ST-	Name of seismic traverse of refraction prospecting

Notes :
1), */ ; The elevations of the drillholes are temporarily referred to the "1/25,000-scale map" made up from air-photographs in 1984.
2), Geological logs of the drillholes DT-1 and -2 are shown in DWG. 5-6

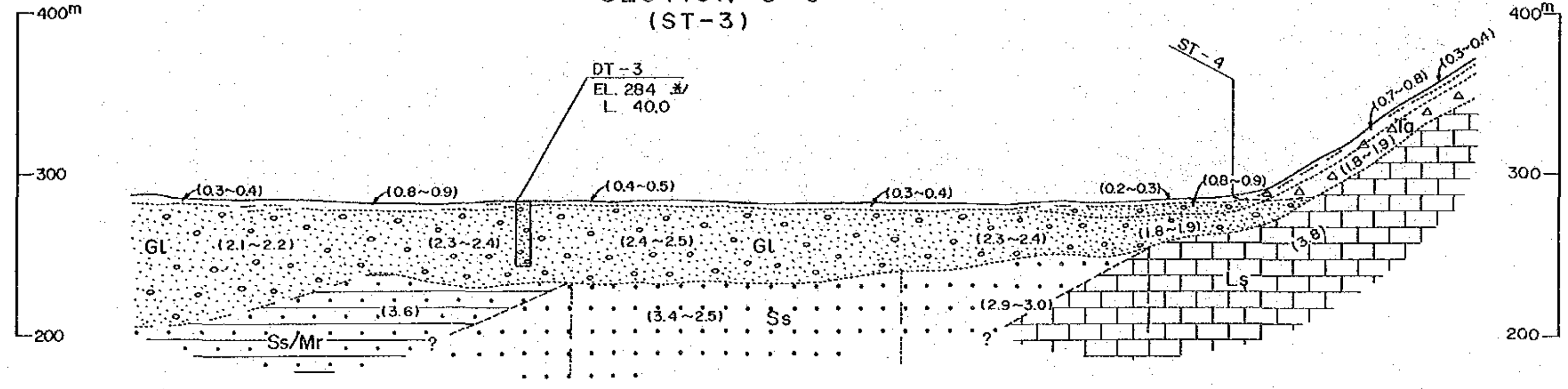
0 — 200m

ENE RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

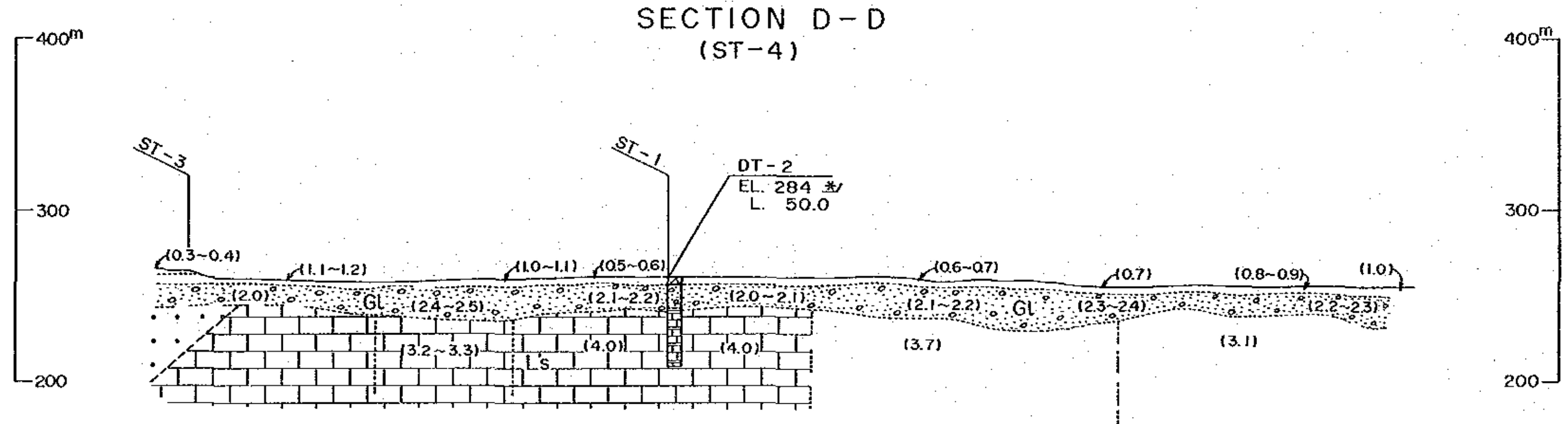
GEOLOGICAL SECTION OF TAMBO PUERTO PRADO SITE

DWG. 5-5

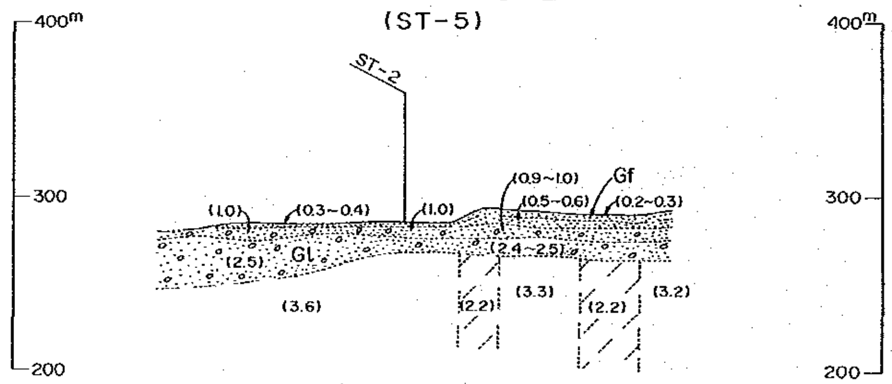
SECTION C-C
(ST-3)

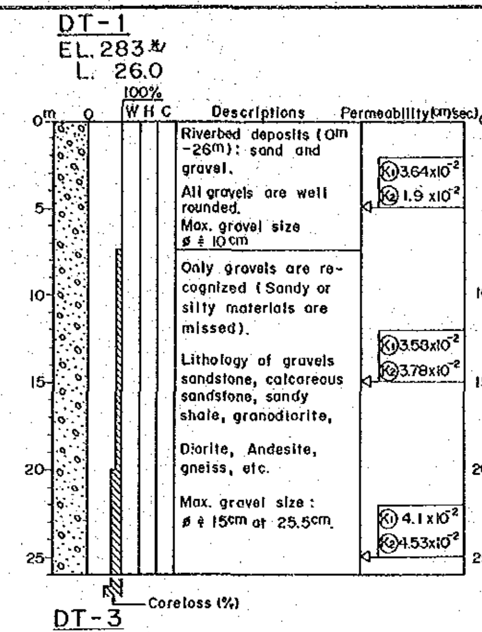


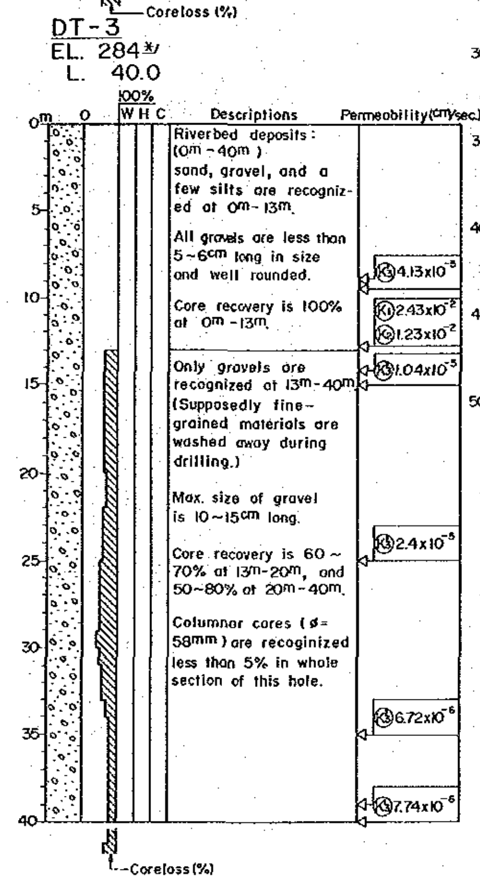
SECTION D-D
(ST-4)

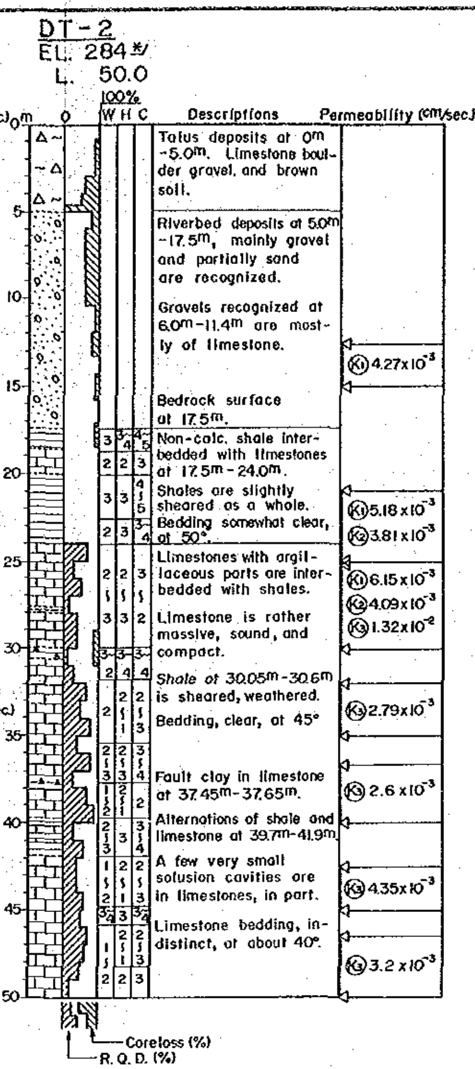


SECTION E-E
(ST-5)

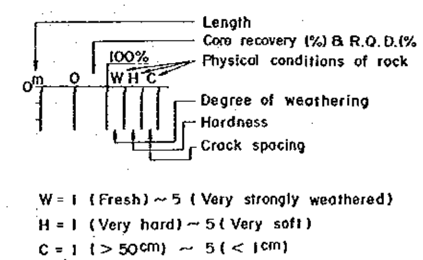








LEGEND
(Log of Drillhole)



W = 1 (Fresh) ~ 5 (Very strongly weathered)
H = 1 (Very hard) ~ 5 (Very soft)
C = 1 (> 50cm) ~ 5 (< 1cm)

Explanations of Pemeability

Section tested for permeability

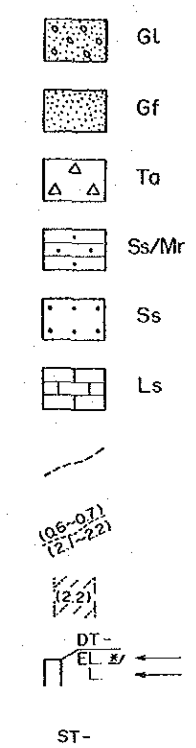
K1 : Permeability value by open-end constant load method (in cm/sec.)

K2 : Permeability value by open-end constant load method (in cm/sec.)

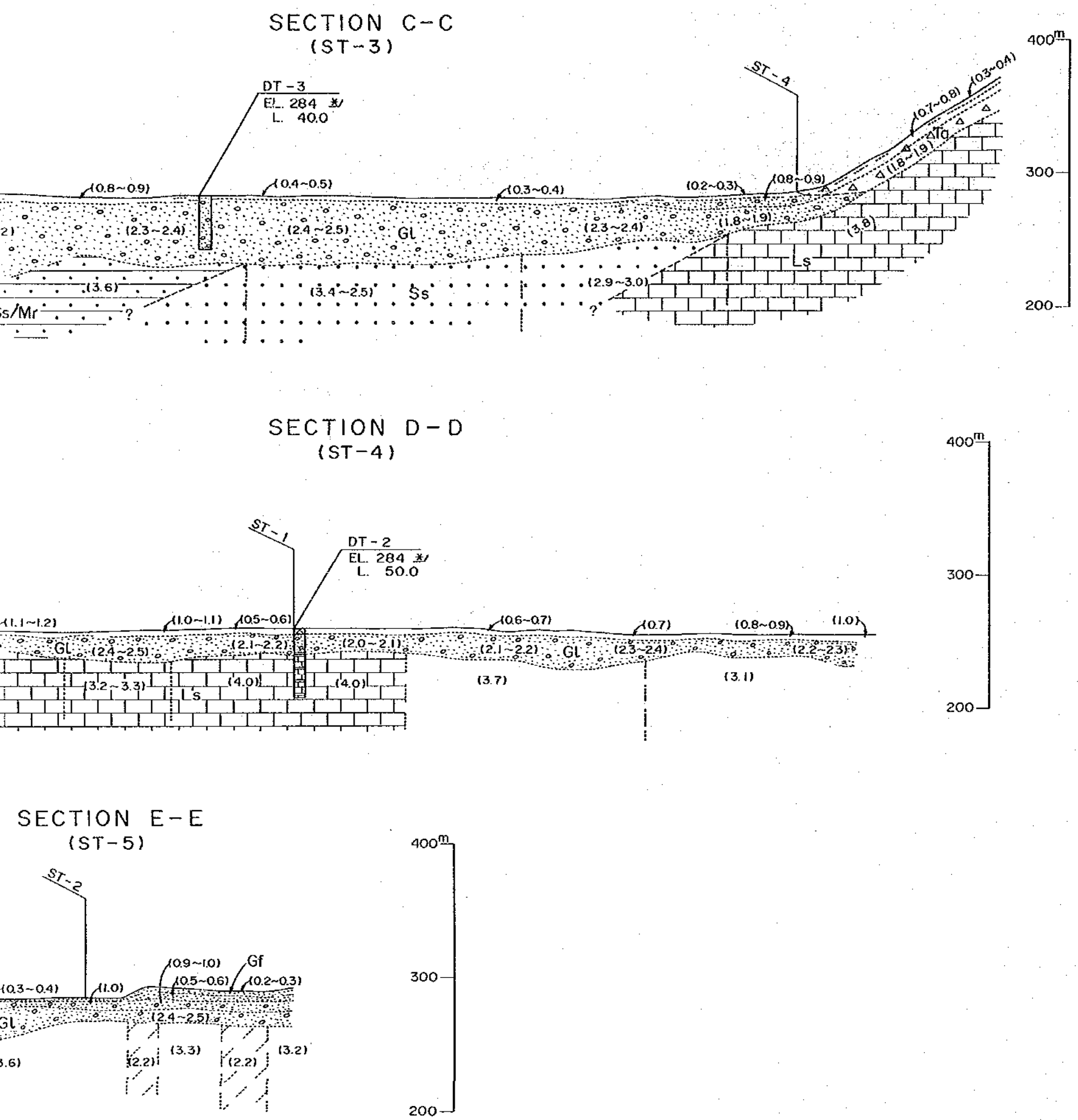
K3 : Permeability value by open-end variable load method (in cm/sec.)

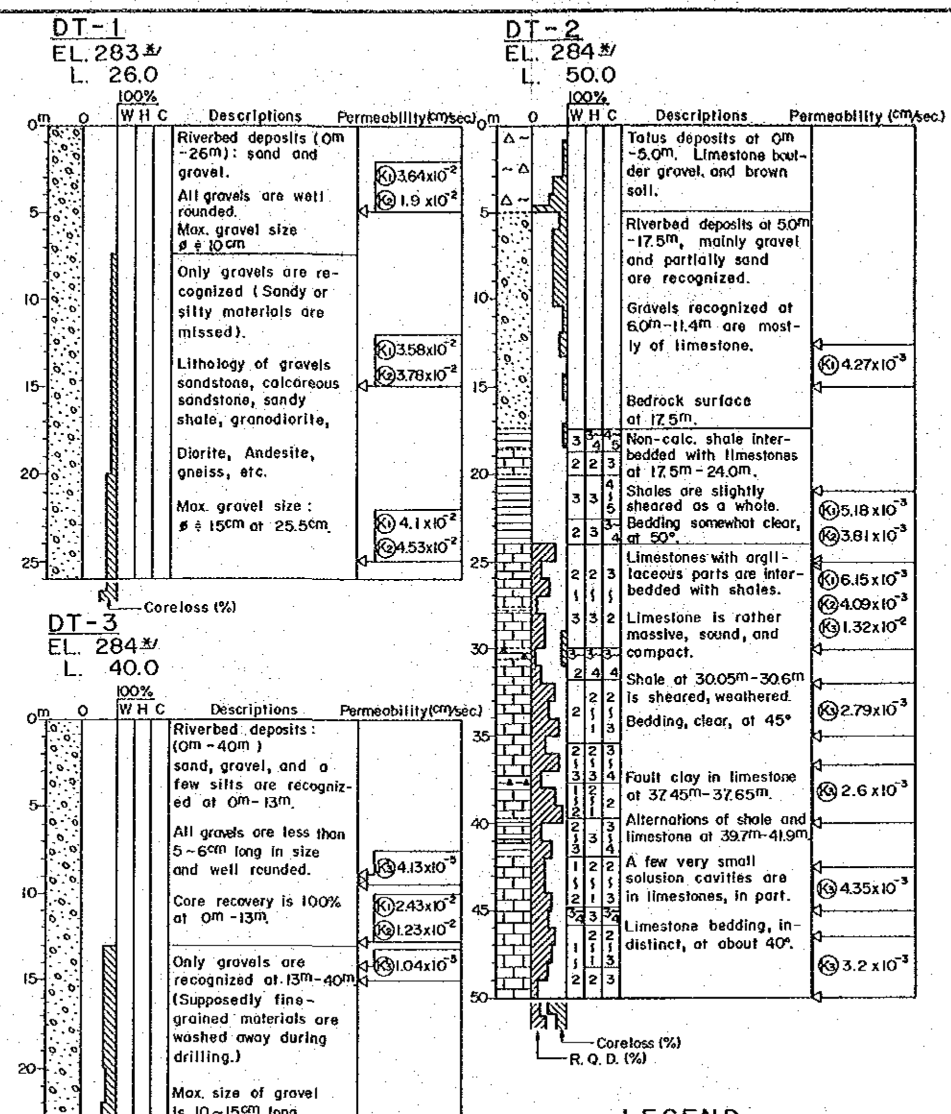
(Le Franc Type) **/

K4 : Permeability value by packer method with constant load (in cm/sec.) (Lugeon Type) **/



Notes : */ ; refer air -
**/ ;





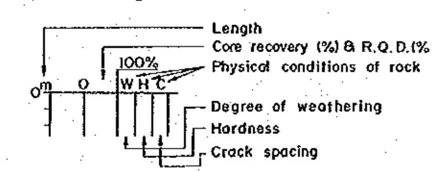
LEGEND
(Sections)

- Gl — Riverbed deposits (Silt, sand, gravel)
- Gf — Flood plane deposits (Silt, sand, gravel)
- Ta — Talus deposits (Silt, clay, rock fragments)
- Ss/Mr — Alternation of sandstone, and marl
- Ss — Siliceous sandstone (Interbedded with marl or shale)
- Ls — Limestone (Interbedded with marl or shale)
- Geological boundary
- (0.6~0.7) (2.1~2.2) — Seismic primary wave velocity (in km/sec.) and its boundary
- (2.2) — Relatively low velocity zone (in km/sec.)
- DT- / EL. */ / L. — Drillhole's name / Elevation (in m.) / Length (in m.)
- ST- — Name of seismic traverse of refraction prospecting

Notes : */ ; The elevations of the drillholes are temporarily referred to the "1/25,000 - scale map" made up from air - photographs in 1984.

**/ ; Detailed explanations are given in Appendix - A-2 (7)

LEGEND
(Log of Drillhole)



W = 1 (Fresh) ~ 5 (Very strongly weathered)
H = 1 (Very hard) ~ 5 (Very soft)
C = 1 (> 50cm) ~ 5 (< 1cm)

Explanations of Pemeability

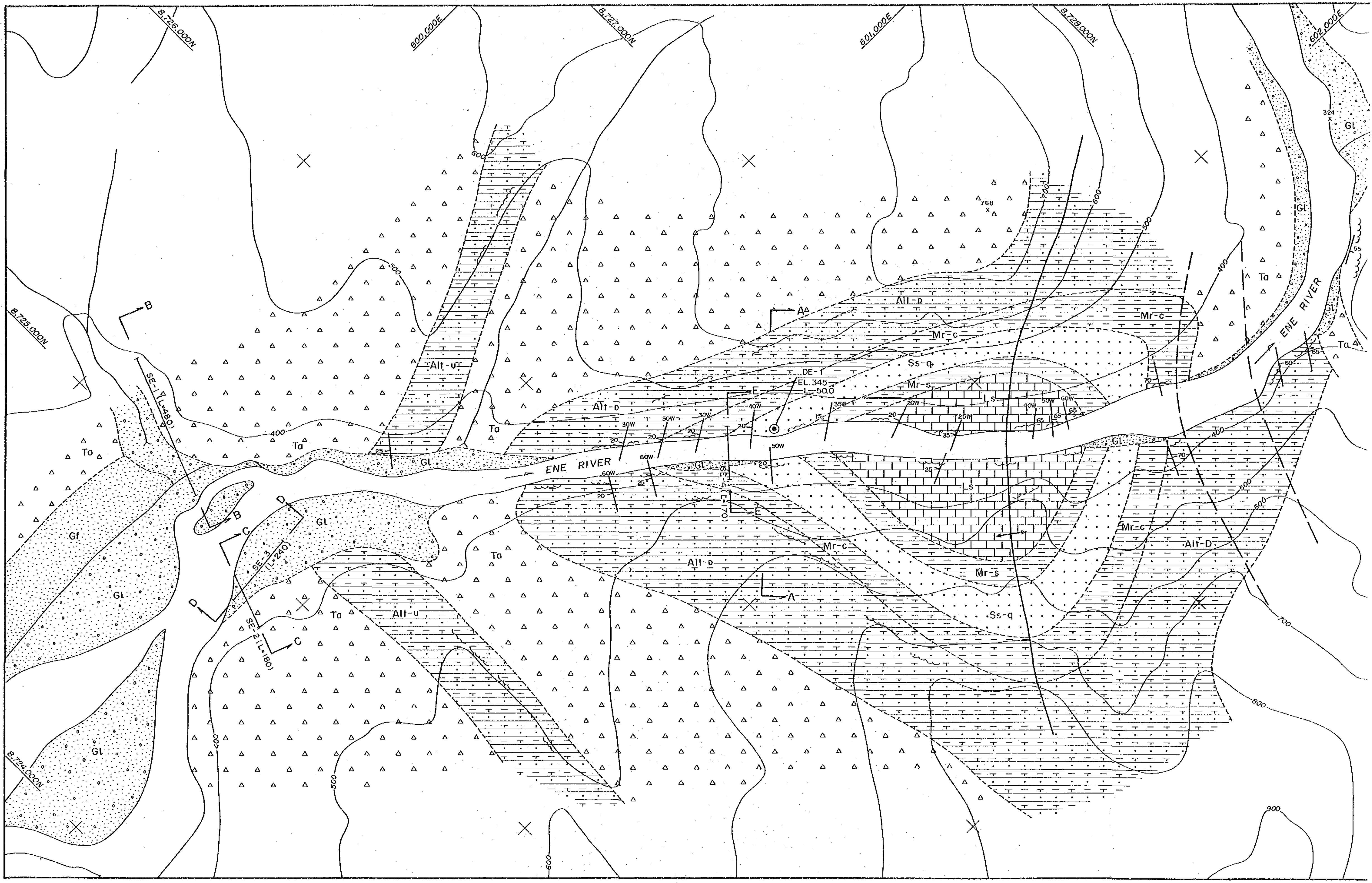
- Section tested for permeability
- (K) : Permeability value by open-end constant load method (in cm/sec.)
- (K) : Permeability value by open-end constant load method (in cm/sec.) (Le Franc Type)**/
- (K) : Permeability value by open-end variable load method (in cm/sec.)
- (K) : Permeability value by packer method with constant load (in cm/sec.) (Lugeon Type)**/

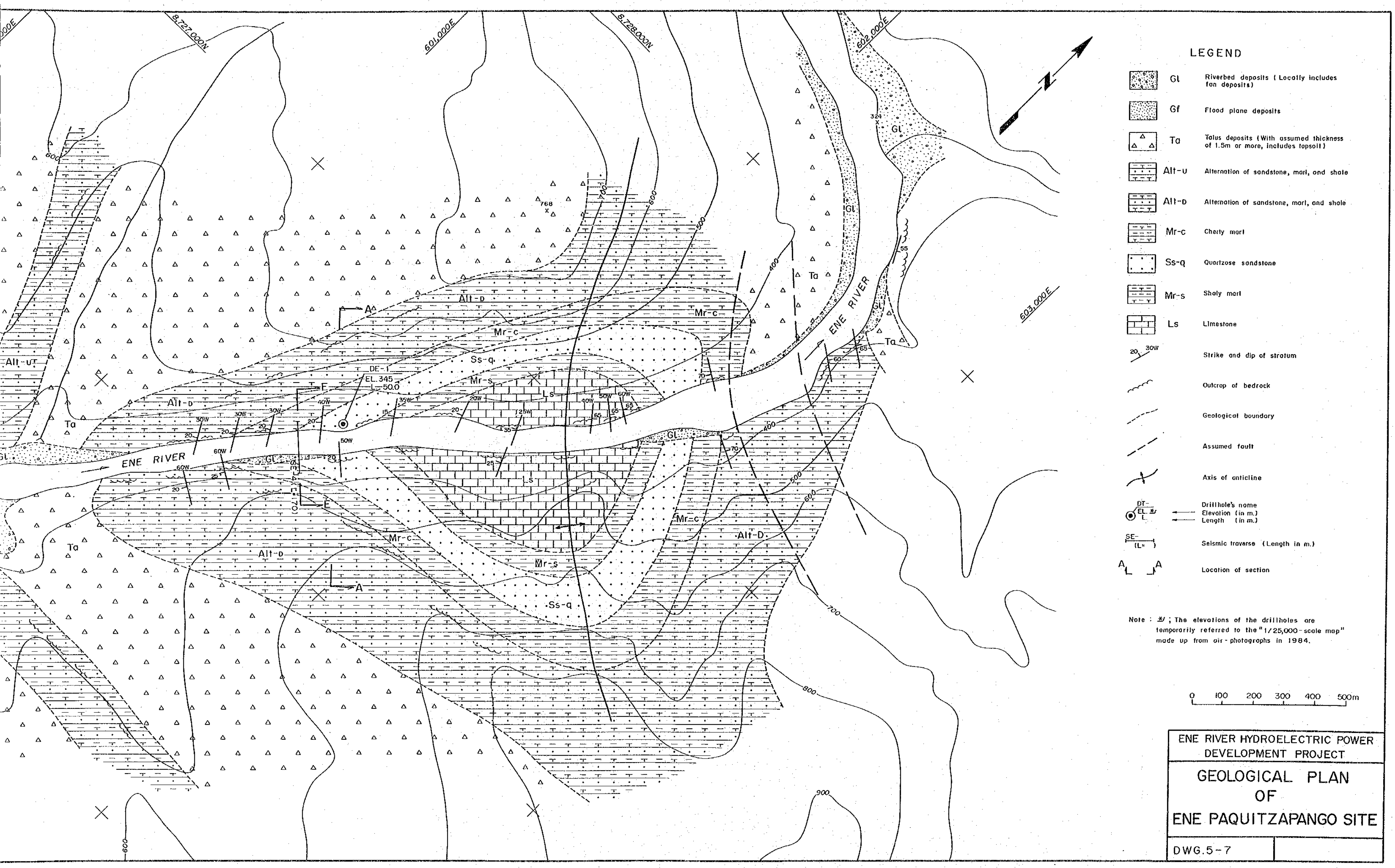
0 — 200m

ENE RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL SECTIONS AND LOG OF DRILLHOLE OF TAMBO PUERTO PRADO SITE

DWG. 5-6


8,726,000N
600,000E
8,727,000N
601,000E
8,728,000N
602,000E
8,725,000N
8,724,000N
ENE RIVER
ENE RIVER
DE-1
EL. 345
L=50.0
SE-1 (L=480)
SE-2 (L=180)
SE-3 (L=240)
SE-4 (L=170)
Alt-u
Alt-D
Mr-c
Ss-q
Mr-s
Ls
Ta
Gl
Gf
400
500
600
700
800
900
768
324

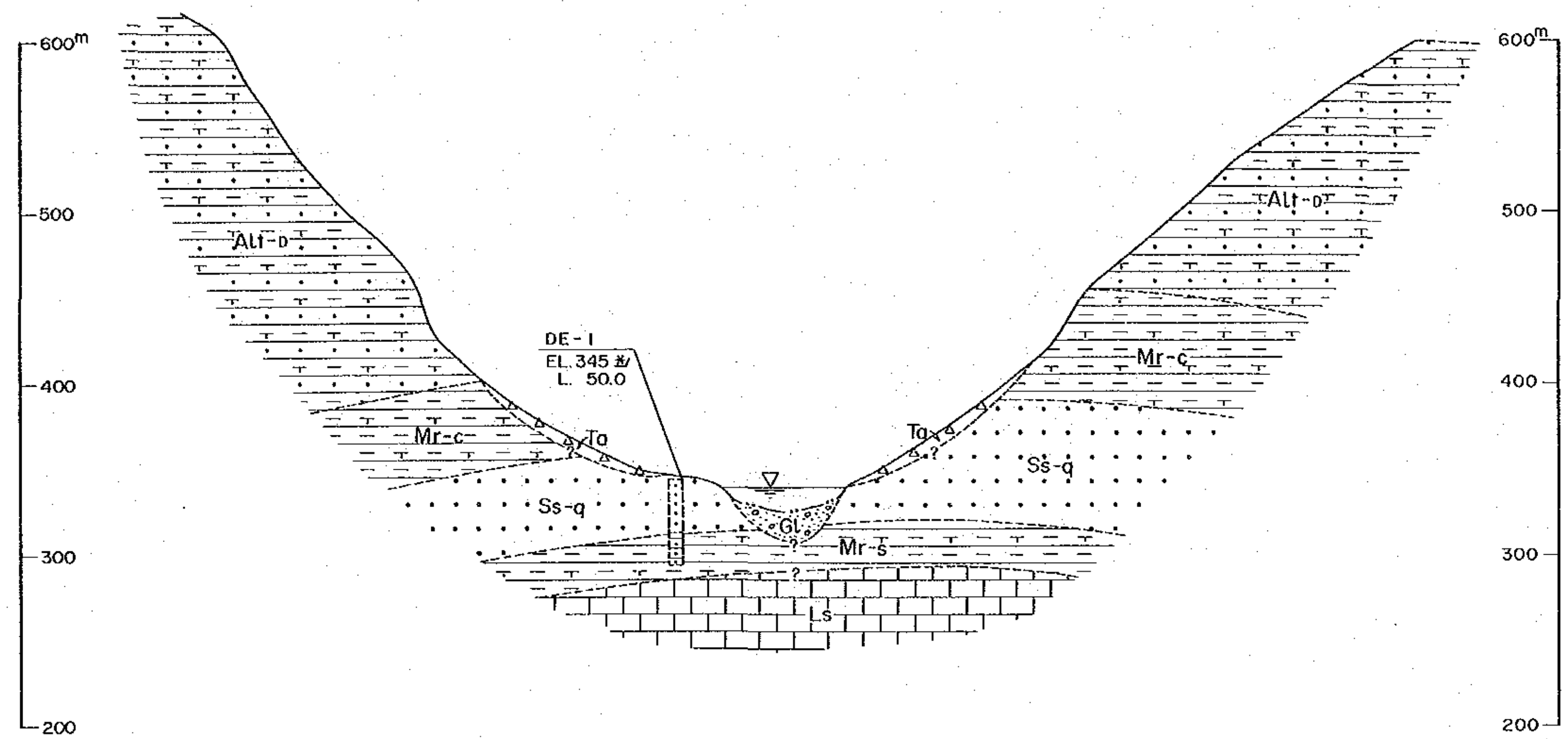


ENE RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL PLAN OF ENE PAQUITZAPANGO SITE

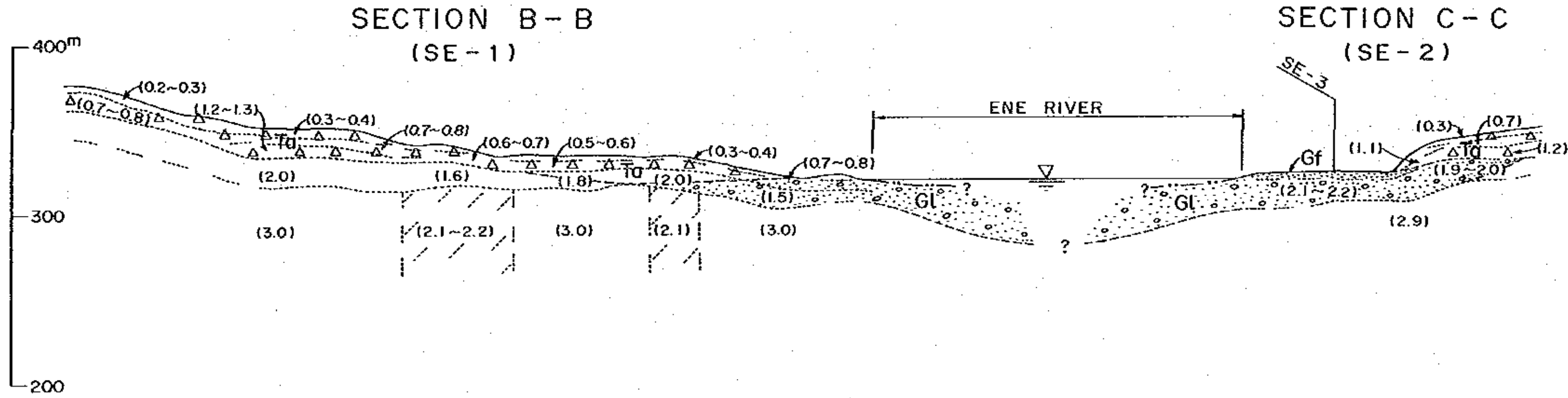
DWG.5-7

SECTION A – A

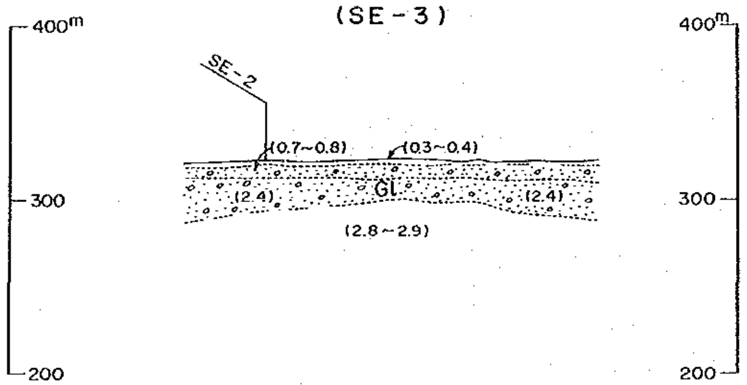


SECTION B – B (SE – 1)

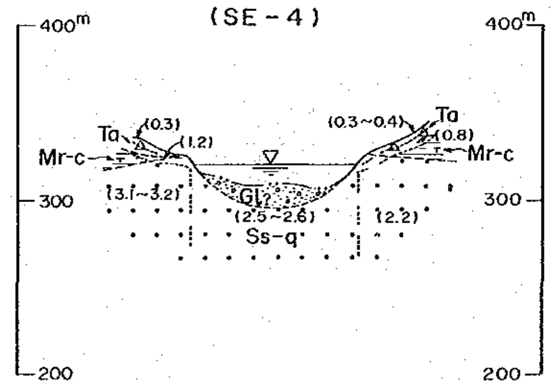
SECTION C – C (SE – 2)

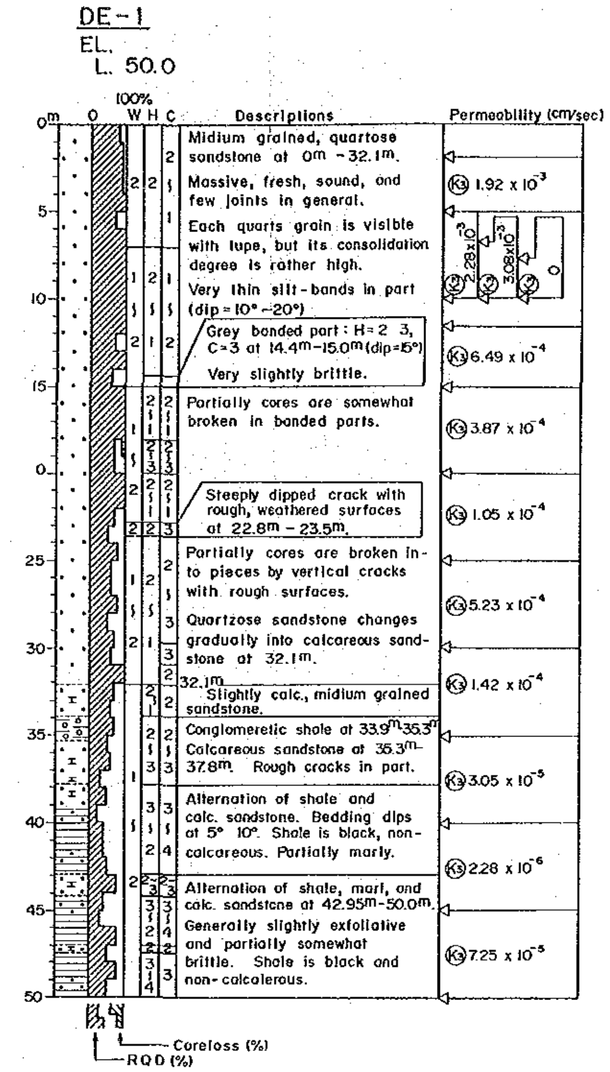


SECTION D – D (SE – 3)

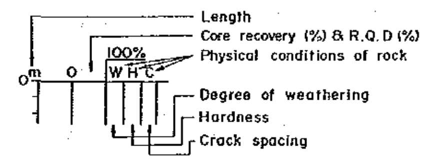


SECTION E – E (SE – 4)





LEGEND
(Log of Drillhole)



W = 1 (Fresh) ~ 5 (Very strongly weathered)
H = 1 (Very hard) ~ 5 (Very soft)
C = 1 (> 50cm) ~ 5 (< 1cm)

Explanations of Permeability

Section tested for permeability

K1 : Permeability value by open-end constant load method (in cm/sec.)

K2 : Permeability value by open-end constant load method (in cm/sec.)

K3 : Permeability value by open-end variable load method (in cm/sec.)

(Le Franc Type) **/

K4 : Permeability value by packer method with constant load (in cm/sec.) (Lugeon Type) **/

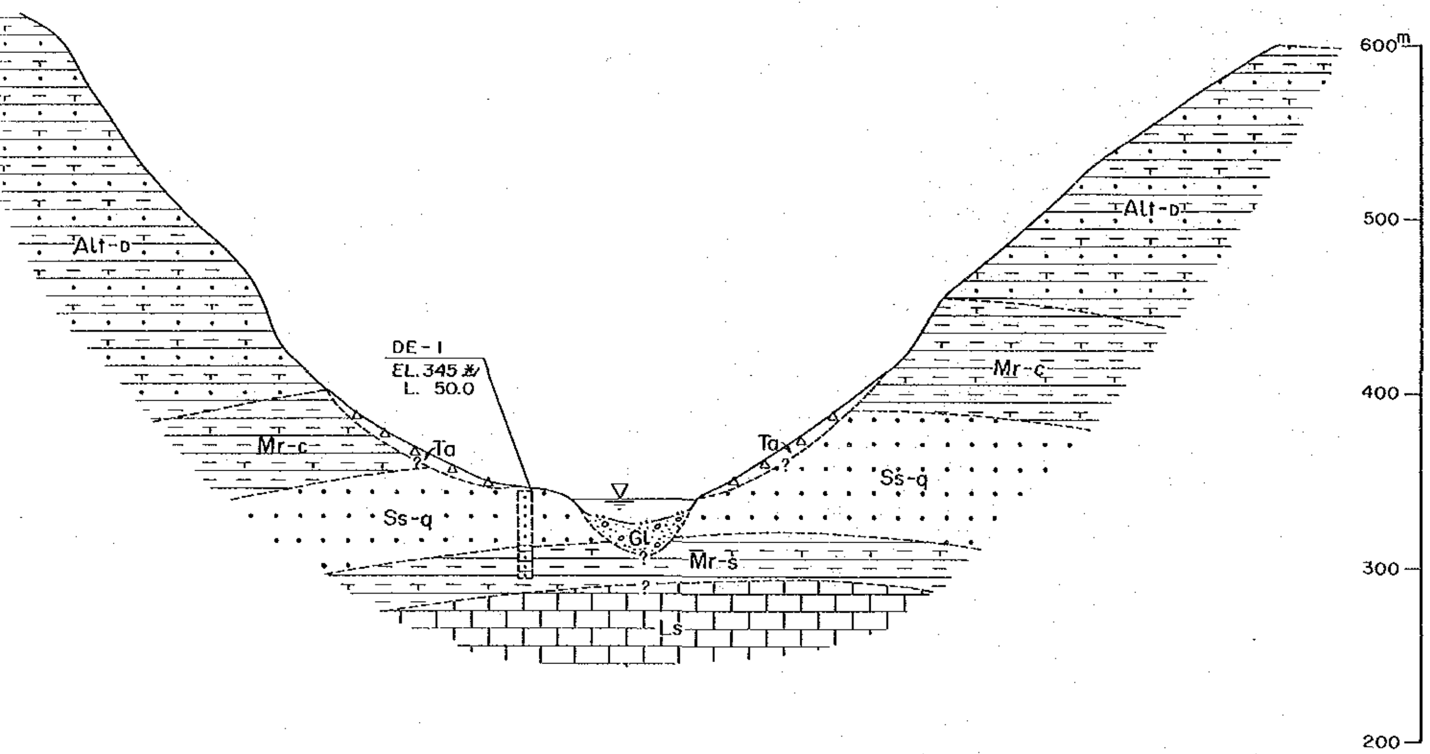
LEGE
(Secti

Gl — Riverbe
Gf — Flood p
Ta — Talus d
Alt-D — Alternat
Mr-c — Cherfy
Ss-q — Quartz
Mr-s — Shaly
Ls — Limest
Geologi
Bottom
(1.2) (3.2) — Seismic its bou
(2.1) — Relativ
DT- EL. */ L. — Drillhol Elevati Length
ST- — Name of refr

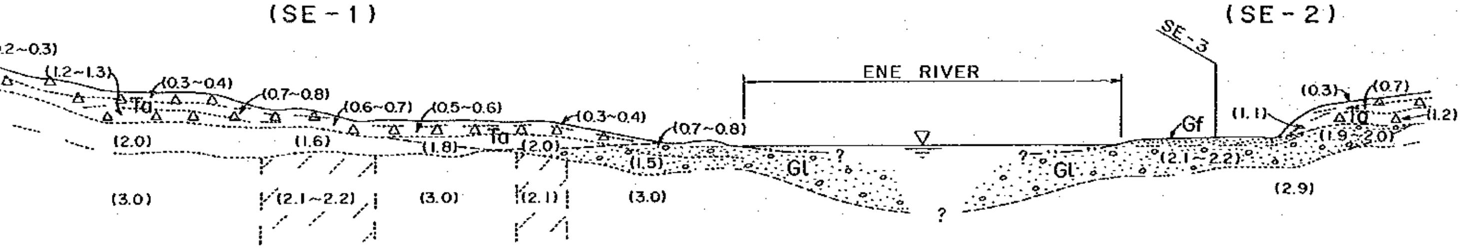
Notes : */ ; The ele referred made u

**/ ; Detailed

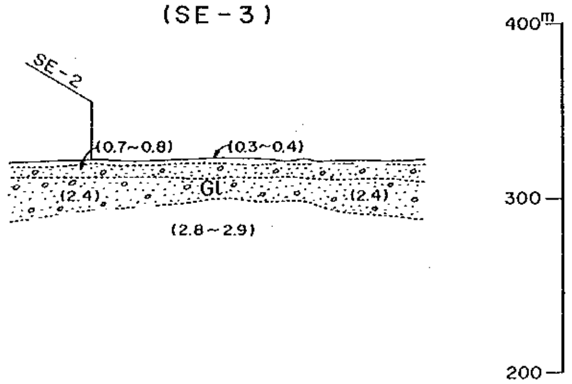
SECTION A－A



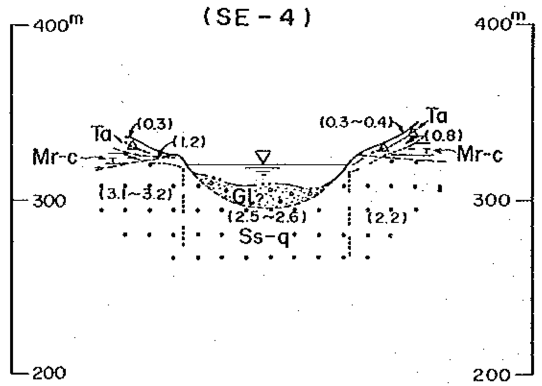
SECTION B－B (SE－1)　SECTION C－C (SE－2)

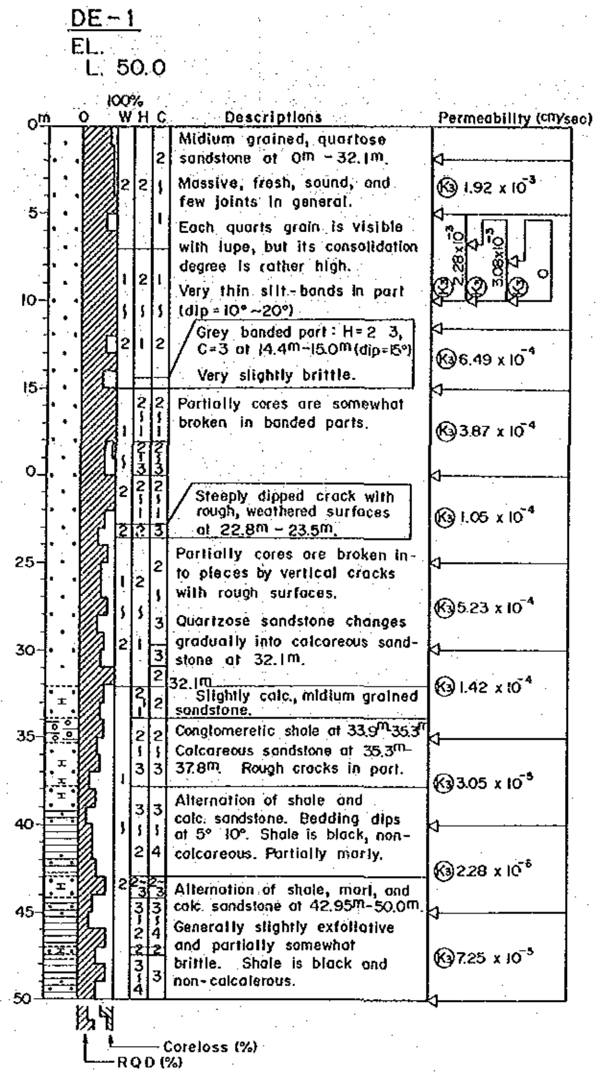


SECTION D－D (SE－3)

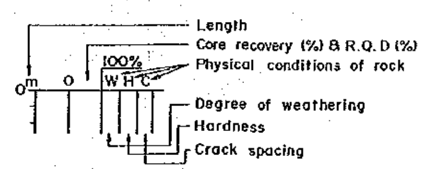


SECTION E－E (SE－4)





LEGEND (Log of Drillhole)



W = 1 (Fresh) ~ 5 (Very strongly weathered)
H = 1 (Very hard) ~ 5 (Very soft)
C = 1 (> 50cm) ~ 5 (< 1cm)

Explanations of Permeability

Section tested for permeability

- K1 : Permeability value by open-end constant load method (in cm/sec.)
- K2 : Permeability value by open-end constant load method (in cm/sec.) — (Le Franc Type) ※※
- K3 : Permeability value by open-end variable load method (in cm/sec.)
- K4 : Permeability value by packer method with constant load (in cm/sec.) — (Lugeon Type) ※※

LEGEND (Sections)

Gl	Riverbed deposits (Silt, sand, gravel)
Gf	Flood plane deposits (Silt, sand, gravel)
Ta	Talus deposits (Clay, silt, rock fragments)
Alt-D	Alternation of sandstone, marl, and shale
Mr-c	Cherty marl
Ss-q	Quartzose sandstone
Mr-s	Shaly marl
Ls	Limestone
	Geological boundary
	Bottom of river water (By echo sounding device, on 31 st Oct, 1984)
(1.2) (3.2)	Seismic primary wave velocity in (km/sec.) and its boundary
(2.1)	Relatively low velocity zone (in km/sec)
DT- EL. ※ L.	Drillhole's name, Elevation (in m.), Length (in m.)
ST-	Name of seismic traverse of refraction prospecting

Notes : ※ ; The elevations of the drillholes are temporarily referred to the "1/25,000-scale map" made up from air-photographs in 1984.

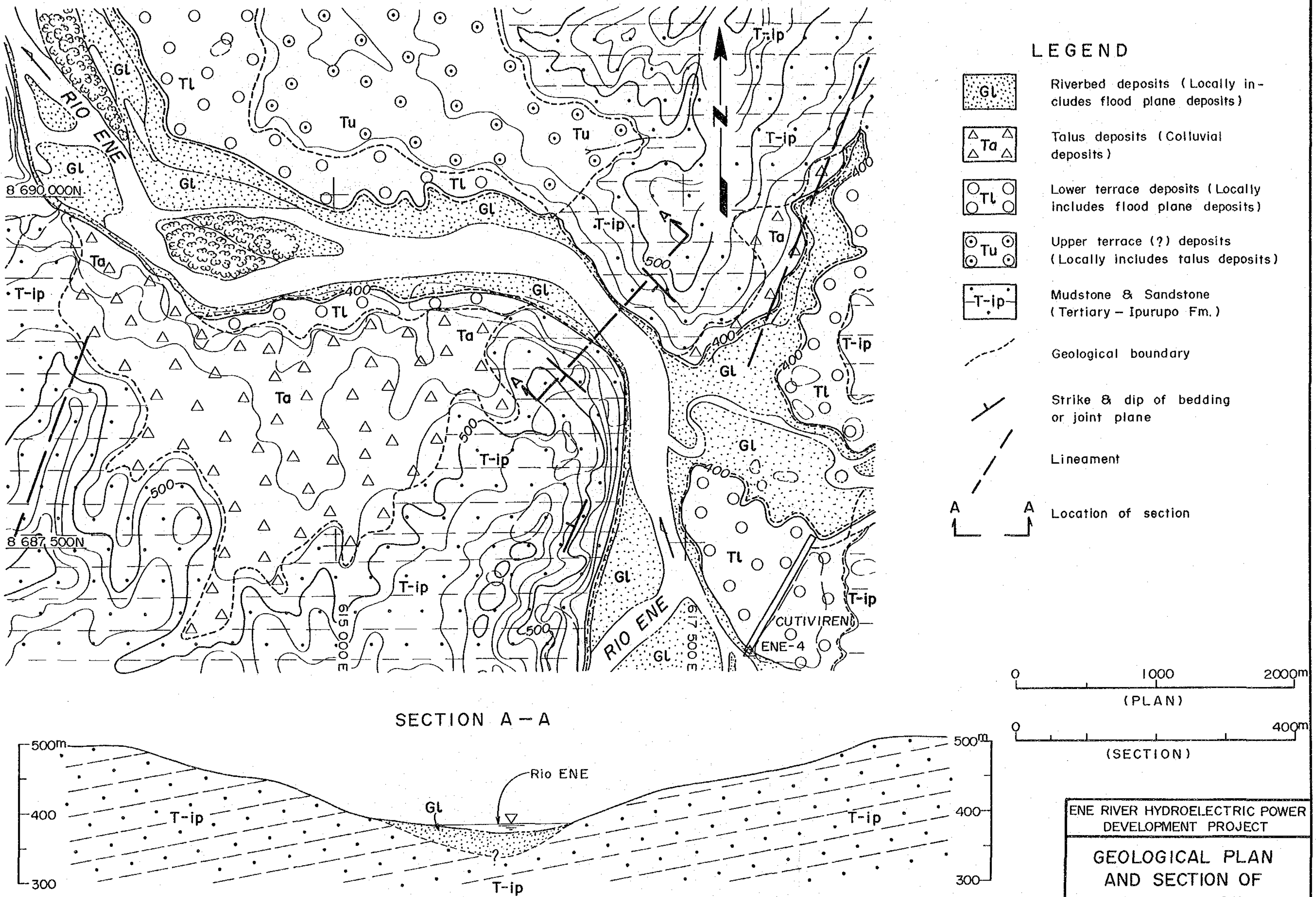
※※ ; Detailed explanations are given in Appendix-A-2 (7)

0　200m

ENE RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL SECTIONS AND LOG OF DRILLHOLE OF ENE PAQUITZAPANGO SITE

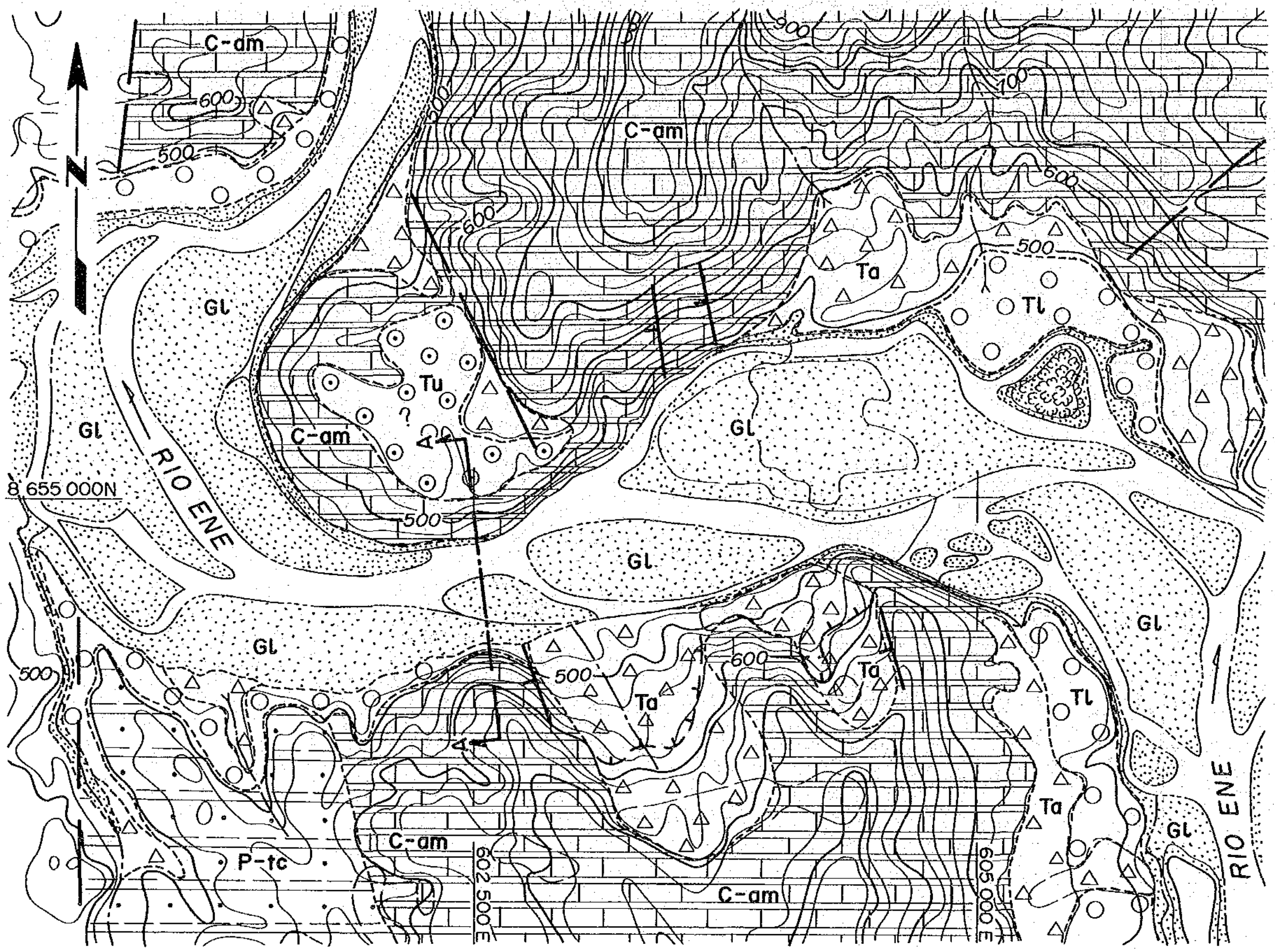
DWG. 5-8



ENE RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL PLAN AND SECTION OF CUTIVIRENI SITE

DWG.5-9



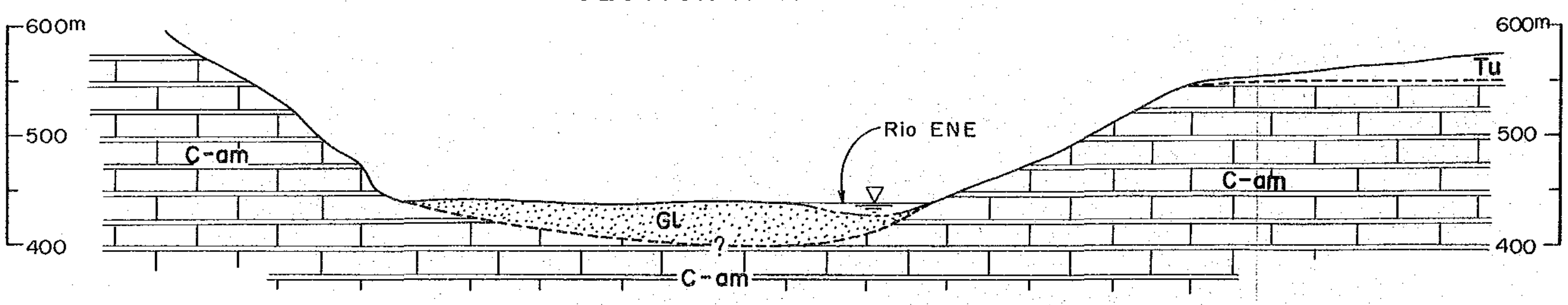
LEGEND

- Gl — Riverbed deposits (Locally includes flood plane deposits)
- Ta — Talus deposits (Colluvial deposits)
- Tl — Lower terrace deposits (Locally includes flood plane deposits)
- Tu — Upper terrace (?) deposits (Locally includes talus deposits)
- P-tc — Shale, Sandstone & Marl (Permian: Tarma- Copacabana Fm.)
- C-am — Limestone & Shale (Carboniferous: Ambo Gp.)
- Geological boundary
- Strike & dip of bedding or joint plane.
- Slope failure
- Lineament
- A A — Location of section

0 1000 2000m
(PLAN)

0 400m
(SECTION)

SECTION A-A



ENE RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

GEOLOGICAL PLAN AND SECTION OF SUMABENI SITE

DWG. 5-10

CHAPTER 6 DEVELOPMENT SCHEME

CHAPTER 6 DEVELOPMENT SCHEME

CONTENTS

CHAPTER 6 DEVELOPMENT SCHEME

6.1 General

The power demand of Peru, particularly of the Central-North System centered at Lima, has been growing steadily, and hydroelectric power development projects to effectively utilize the abundant runoff of the upstream Amazon River which is a precious hydroelectric power source of Peru have been studied to meet this increasing demand. In this chapter, a study is made concerning formulation of a Master Plan of the optimum integrated hydroelectric development plan for the entire Ene River Basin including the upstream part of the Tambo River and the Perene River.

6.1.1 Dam Sites

In the area of the Ene River investigated, there have been several proposed sites for dam construction from the past, and in the investigations made this time also, it was confirmed that sites with possibilities for dams resulted in the four locations of Tambo Puerto Prado, Ene Paquitzapango, Ene Cutivireni, and Ene Sumabeni. The outlines of the topographies and geologies of the abovementioned dam sites are described in Chapter 5 "Geology", and it is judged that comparatively large-scale dams can be constructed at the Tambo Puerto Prado and Ene Paquitzapango sites.

However, for the two other dam sites, Ene Cutivireni and Ene Sumabeni, geological investigations (boring, seismic prospecting) have not been carried out this time, but as described in detail in Chapter 5 "Geology", they are judged from site reconnaissances, geological interpretations of aerial photographs and topographical map newly prepared not to be superior to the Ene Paquitzapango and Tambo Puerto Prado sites either topographically or geologically.

Regarding these two sites, it will be necessary for further geological investigations to be made, upon which the study in this chapter is to be supplemented.