3.4 Site Geology

3.4.1 Nam Mae Ngao No. 2

1) Reservoir

The Ngao river which will form the reservoir flows down in a direction which is harmonious with the SSE-NNW geological structure. The slopes at both banks are steep as a whole, but terrace landsforms can be seen along the river to approximately 6 km upstream from the dam site and there are scattered places where the river-bed width is increased.

The geology of the reservoir along the Ngao river, according to the results of surface reconnaissances, consists mainly of alternating beds of sandstone and shale, with lenses of limestone intercalated in small scale. Loosening due to weathering can be seen in the sandstone and shale alternations.

The geology was estimated by photogeological interpretations for parts upstream of Nam Mae Ngao No.3 dam site and parts of high elevation at the both-bank sides of the dam site. According to the results, the part higher than about EL. 300 m at the right bank of the reservoir and that above EL. 400 to 500 m at the left bank are massive on the whole, but partially, there are irregular topographies and sinkholes thought to be due to solution, and it is assumed limestone is distributed. Below these parts, it is estimated that sandstone and shale alternations are distributed similarly to the vicinity of the dam site.

As lineaments, there is one that is predominant along the Ngao river which is distinct and has good continuity. This lineament is found to the east of the Yuam river by which the continuity has been confirmed.

According to existing data "NAM MAE YUAM Hydroelectric Development Project Feasibility Report" (by JICA, March 1984), a fault corresponding to this lineament has been confirmed to the east of the upstream Yuam river, and the character of its fault has been reported as it has NNW-SSE strike and almost vertical dip, and the width of shear zone is a few meters.

The distributions and properties of limestone and lineament may be cited as problems regarding the aspect of reservoir watertightness.

It is assumed that the limestone which runs approximately parallel with the Ngao river at 1.5 km to 2.5 km distant from the river is distributed in the both banks of the reservoir higher than the high water level of 260 m, and the scale of limestone intercalated in alternating beds of sandstone and shale is assumed to be small.

However, the detailed geological surveyes concerning these matters are considered to be necessary in the future.

The thicknesses of ridges at both banks near the dam site are small, and there is concern about possible leakage through intercalated limestone layers that have become deteriorated.

The lineament passing through the right bank of the dam site and having the best continuity was confirmed to be a fault zone from the results of drilling performed at the right-bank ridge at the dam site. This fault zone has been formed in non-calcareous rock, and although the permeability characteristics are unknown, water level in drillhole is comparatively high, and it is thought there is watertightness. Other lineaments all have poor continuity, and although it is thought they will not pose great problems concerning leakage from the reservoir, it will be necessary for studies to be made in detail regarding those passing through limestone layers.

Landslide configulation and area of collapse in the reservoir have not been confirmed in photogeological interpretations. Under present circumstances, therefore, it is thought there will be no special problem concerning stability of reservoir slopes.

2) Dam Site

A river terrace is developed at the right bank of the dam site, and there are flat areas having widths of approximately 200 m. The slope continuing from this is gradual with a gradient of 20 to 30 deg. On the other hand, terrace landforms are not seen at the left-bank side and the slope is 30 to 35 deg from the river bank.

The right abutment of the dam site has a gully cutting in parallel to the Ngao river, and the ridge at the right-bank side is a scraggy ridge extending in the NNW-SSE direction.

This ridge is narrow, being 100 to 200 m in width, at high water level of 260 m.

Also, the ridge at the left-bank side which extend in NNE-SSW direction is narrow, being 200 m in width, at high water level of 260 m.

The geology of the dam site consists mainly of alternating beds of sandstone and shale.

Further, the limestone bed has been confirmed by drilling executed at the ridges of both-bank sides.

The sandstone and shale alternations are weathered as a whole, with fissility occurring readily, and many parts are brittle.

The strikes of the formations are N30° - 50°W and roughly constant, whereas dips are 60° - 80°SW at the upstream part and 70° - 80°NW at the downstream part, so that an anticline having its anticlinal axis in the NW-SE direction is estimated to exist at the left-bank side of the dam axis.

Terrace deposits, river deposits, and talus deposits are distributed as surface deposits overlying the abovementioned bedrock. Abovementioned terrace deposits are distributed at the flat part of the right bank, and from the fact that outcropping of bedrock cannot be seen at beds of small gullies at the right-bank side, it is thought that layer thickness is fairly great. The constituent materials are silt and sand with a mixture of poorly sorted gravels. River deposits consist of fine to medium-grained sand containing little gravel, and appear not to be very thick. Talus deposits are deposited at mountain skirts and consist mainly of gravel-bearing soil originating from sandstone and shale alternations.

According to the results of photogeological interpretations, there is a fairly distinct lineament with good continuity passing the gully cutting in at the right-bank side parallel to the Ngao river.

Although faults could not be confirmed in the dam site surroundings in surface geological investigations, fault zones have been found in drilling of DR-0 and DR-2 at the right-bank abutment and right-bank ridge. The location of the abovementioned Drillhole DR-0 corresponds roughly with the location passed by the lineament discerned in photogeological interpretations, and it was confirmed that the lineament represents a fault zone.

This site may be evaluated from an engineering geological standpoint as follows based on the geological conditions at the surface and the results of drilling including permeability tests.

- o The river-bed portion and parts of low elevation at the right and left banks consist of bedrock with no problem as a foundation of a rockfill dam with respect to both load bearing capacity and permeability.

- o Weathering is prominent at the ridge portion on the left-bank side, and according to Drillhole DL-1 made at this ridge portion, strong weathering has occurred to a depth of 41 m (elevation approximately 261 m), with many sections where cores could not be recovered, and there is a problem regarding load bearing capacity. Meanwhile, it was not possible to perform permeability tests on this section. This indicates that the geology of this section is very cracky and there will be a problem of permeability. Therefore, since the thickness of the ridge upstream at the high water level elevation is approximately 200 m and small, there will be a problem of watertightness of the ridge at the strongly weathered portion.

- o The part beyond a depth of 41 m in Drillhole DL-1 consists of limestone. This limestone is comparatively hard, and it is thought there will be no problem about load-bearing capacity. With regard to permeability, packers could not be installed in most sections so that it is unknown, but from the facts that loss of drilling water was seen immediately upon entering the limestone, that sections with core loss and solution cracks were seen, and that the ground-water table in the drillhole was low at a depth of 89.0 m (EL. 213.4 m), it is imagined that permeability will be high.

Consequently, a thorough study of water cut-off plans will be required with respect to the left abutment where this limestone is distributed.

There is also a possibility that limestone is interbedded at a ridge upstream, and it will be necessary for the weathered condition of this ridge portion to be grasped and investigations made on the distribution and permeability of the limestone, and on the ground-water table to contemplate water cut-off treatment.

Still further, it is estimated that there is an anticlinal axis at the left-bank side so that it can be expected that limestone will be distributed at low-elevation parts also, and it will be necessary for this to be confirmed hereafter.

o With regard to the right abutment and the right-bank ridge portion, the existence of a fault zone and the distribution of limestone at the ridge portion can be cited as geological problems.

o The fault zone has been confirmed by Drillholes DR-0 and DR-2 provided at the right-bank abutment and ridge. The sheared zone of Drillhole DR-0 is developed in sandstone near the boundary between limestone and sandstone, and it is estimated to extend upstream and downstream of the dam crossing the right-bank ridge in a manner to run along the photo lineament interpreted from aerial photographs.

Concerning permeability of the sheared zone, it is of unknown nature since permeability tests were not performed, but the ground-water table in the drillhole was comparatively high and loss of drilling water was not seen so that it is thought this sheared zone is watertight. However, since the existence of cracky portions is expected around the fault zone, it will be necessary for investigations to be made hereafter concerning the cracking condition and permeability of the bedrock in the vicinity of the sheared zone.

o The limestone at the right-bank ridge portion is estimated to be distributed at the upstream and downstream sides of the dam crossing the right-bank ridge downstream of the dam axis, similarly to the sheared zone. According to the results of Drillhole DR-1 provided at the ridge, there are sections of core loss and solution cracks in the limestone, but with regard to permeability, other than a part of a high 35 to 49 Lu at shallow depths, the values are generally of the order of 10 to 20 Lu. However, the ground-water table in the drillhole is low at a depth of 54.0 m (EL. 217.2 m), and there will be concern about leakage of stored water from the ridge portion since its thickness is small, and there will be a necessity for water cut-off treatment of the ridge portion to be provided.

o At the stage of a preliminary design, the dam axis was selected taking into consideration of these topographical and geological conditions.

This dam axis is located at approximately 150 m upstream of dam axis on which geological investigation works were executed. On the selected dam axis, no investigation works have been done at this time.

As described above, there are many problems concerning topography and geology at this site, such as problems of leakage from the righ- and left-bank ridges. Therefore, it is wished to recommend detailed geological investigation works to be carried out on this dam axis at the stage of a feasibility study.

Table 3-2 Additional Drill Hole in Nam Mae Ngao No.2 Dam Site

Site	Hole No.	Coordinate		Elevation (m)	Direction	Length (m)
Dam	DR-5	1967, 005N	393, 630E	178.0	S70°W, 60°	100.0
	DR-6	1967, 050N	393, 770E	215.0	90°	60.0
	DR-7	1967, 090N	393, 915E	265.0	90°	100.0
Right-bank side ridge	DR-8	1967, 120N	394, 015E	310.0	90°	100.0
Dam	DL-3	1966, 960N	393, 480E	220.0	90°	60.0
	DL-4	1966, 925N	393, 375E	260.0	90°	100.0
Left-bank side ridge	DL-5	1966, 620N	393, 085E	270.0	90°	70.0
	DL-6	1966, 685N	393, 015E	310.0	90°	100.0
	DL-7	1966, 690N	392, 955E	305.0	90°	100.0
Total		9 Holes	790m			

3.4.2 Nam Mae Ngao No. 3

1) Reservoir

This reservoir is planned for a high water level elevation identical to that of Nam Mae Ngao No. 2, and the topographical and geological conditions are as described in 3.4.1-1).

It is considered that the place where the watertightness of the reservoir will be a problem is the saddle at the left-bank side of the dam site. A lineament passes through this saddle in the upstream-downstream direction, and the width of the ridge at high water level elevation of 260 m is only 100 m. Consequently, in this site, the geological conditions of the saddle, especially the permeability and the groundwater condition is of importance.

2) Dam Site

This dam site has topographical and geological conditions that are roughly the same as Nam Mae Ngao No. 2. There is a terrace landform of width approximately 170 m at the right-bank side of the dam site and the slope continuing upward is 30 to 40 deg. In contrast, the left-bank side presents a slightly steep slope of approximately 40 deg and a terrace landform as at the right-bank side is not seen. The mountain body forming the left-bank slope presents a ridge-like topography extending in the upstream-downstream direction, with gullies cutting in deeply from approximately 400 m west of the river bed at the upstream and downstream sides and a kerncol topography said to be formed by faulting is seen. Talus and terrace are seen widely at the dam site and its surroundings and there are few outcrops.

The geology of the dam site consists of alternating beds of sandstone and shale, and there is a very small distribution of limestone at the right-bank side downstream of the site. Weathering has occurred in the sandstone and shale alternations, and although slightly brittle, these rocks present a massive condition as a whole. The limestone is hard and solution was hardly seen in surface reconnaissances. Terrace deposits, river deposits and talus deposits cover these bedrocks widely over parts of low elevation of both banks. The terrace deposits and river deposits consist of sand-gravel with gravel diameters 10 to 30 cm. The talus deposits consist of gravel-bearing soil originating from the sandstone and shale alternations. The thicknesses of these deposits are assumed to be fairly great judging by the topography and conditions of outcrops.

There is a very small amount of outcropping of shale in the vicinity of the gully feeding into the Ngao river from the right-bank side approximately 600 m upstream from the dam axis. A shear zone of width about 1.5 m is seen at this outcrop, the strike and dip of which is N20°W, 90°, and a direction harmonious with the lineament passing through the river bed in the upstream-downstream direction discovered in photogeological interpretation is indicated.

Of the lineaments in the vicinity of the dam site, the one cutting across the ridge-like topography at the left abutment of the dam site in the upstream-downstream direction is the most prominent, and this lineament is continuous from the one seen at the right bank of the Nam Mae Ngao No. 2 dam site. Other than this, there is the beforementioned lineament passing through the riverbed portion of the dam site in the upstream-downstream direction, which branches into two lines at the upstream part. The estimated locations of both lineaments are close to the projected dam site, and its geological character will be problem.

3.4.3 Upper Mae Yuam 1

1) Reservoir

River terraces are seen along the river in the reservoir area, and a wide valley topography (valley width of 0.5 to 1.0 km at design high water level) is formed. Besides these flat areas along the river, there are also scattered flat areas at EL. 300 to 400 m (relative height from river bed 50 to 100 m) from Mae La Noi to Mae La Luang on National Highway No. 108 east of the reservoir.

On estimating the geology of the reservoir are from the results of photogeological interpretations, there are terrace deposits along the river at the reservoir, while at the slopes along the river, it is thought there are outcrops of bedrock consisting mainly of sandstone and shale continuing from the dam site. On the other hand, at the flat area found at the east of the reservoir, the distribution of well-sorted sand and gravel has been confirmed as a result of surface reconnaissances. These deposits can be considered to be high-level terraces, but because there is a large relative height (50 - 80 m) from the present river bed, the stratum thickness of the whole is large (approximately 50 to 80 m), and the range of distribution is limited, it is conceivable that there are lacustrine deposits which covered the sedimentary basin formed in the project area from the Tertiary to Quaternary Periods. As for the dissected mountain topography clearly discerned in photogeological interpretations, it is thought the erosion in those times was greatly involved.

Lineaments recognized in the surroundings of the reservoir by photogeological interpretations are developed roughly along the strikes of formations (N-S, NNW-SSE), and there are three lineaments seen at the right-bank side of the dam site which continue on to the reservoir. It was not possible to confirm these lineaments in the field.

According to the results of core drillings which executed at both abutments of the dam site, limestone beds are confirmed in the alternating bed of sandstone and shale.

From the facts that the strike of the bed is parallel to the Yuam river, there should be no problem about water leakage from the reservoir to the direction orthogonal to the river.

However, the ridge in the vicinity of the dam site, especially at the left-bank side is narrow, being 150 to 200 m in width, and the strike of the bed is orthogonal to the ridge. So that it needs to take care of water leakage through limestone interbedded with the alternating beds of sandstone and shale. Therefore, it will be necessary for the distribution and character of the limestone in the vicinity of the dam site to be investigated in detail.

Regarding the lacustrine deposits assumed to be distributed at the upper part of the reservoir left bank (east side), it will be necessary for the relation between the reservoir water level and the elevation at which the deposits are distributed to be investigated along with a study of the permeability.

The topographical saddle where the lineament closest to the dam site passes has a width of 350 m at high water level and it is thought there will be some problem concerning watertightness of the reservoir, therefore, it will be necessary to ascertain its properties further. Landslide configurations and areas of collapse are not seen, and under present conditions, reservoir slopes where future instability can be expected are not recognizable.

2) Dam Site

River terraces are developed along streams in the surroundings of the dam site. The widths of the flat planes of terraces in the vicinity of the dam site are more than 200 m. The slopes of the two banks are gentle at 10 to 20 deg at the left-bank side and steep at 30 - 40 deg at the right-bank side for a topography of wide valley width.

The geology in the vicinity of the dam site mainly consists of the alternating beds of sandstone and shale, but limestone beds are confirmed at both abutments of the dam site according to core drilling.

Moreover, estimating from the fact that huge blocks of conglomerate are scattered at the right-bank slope, it is thought conglomerate is intercalated in the alternations of sandstone and shale. In general, there are few outcrops of bedrock, and bedrock at flat parts along the river are widely covered by terrace deposits, at the river bed by river deposits, and at the slopes by talus deposits.

Of the alternating beds of sandstone and shale, there are parts of the sandstone softened by weathering and of shale divided into blocks due to development of joints. Meanwhile, conglomerate confirmed in the form of boulders chiefly contains gravels of diameter around 3 cm, and the lithological character is that of being very hard. The strikes and dips of these formations are N15° - 28°W, 40° - 50°NE, comprising a geological structure roughly parallel to the river and dipping to the upstream side. The terrace deposits developed along the river, and the river deposits consist of sand and gravel containing a large number of cobbles 10 cm in size.

Faults have not been confirmed in the vicinity of the dam site in surface reconnaissances.

A geological problem concerning this site is the permeability properties of the limestone intercalated in the alternating beds of sandstone and shale described in 1) Reservoir. Testing of permeability has been done only once, but according to the result, the permeability is high at 35.4 Lu. The limestone has many sections of core loss, while the existence of solution cracks can be seen in parts. Still further, since a ground-water table cannot be seen inside the drillhole, it is expected that permeability is high as a whole.

At the left-bank side of the dam site, there is a scraggy ridge of width 150 to 200 m at high water level elevation extending parallel to the dam axis. The strike of the strata is perpendicular to this ridge, while at the thin ridge on the left-bank side, there is concern about leakage from the reservoir through limestone layers.

The dam axis where the above drilling was done was selected on a 1:50,000 topographical map. As a result of examination by a 1:5,000 topographical map newly obtained, a site approximately 200 m downstream where the valley width is slightly narrowed was selected as the new dam axis. This site is more advantageous than the upstream dam site since the dam crest length will be shortened and the dam volume decreased. But, the geological conditions are considered to be more or less the same as at the upstream dam site, and the abovementioned problem is thought to be applicable to this site also.

3.4.4 Upper Mae Yuam 2

1) Reservoir

Compared with the dam site, river terraces are not well-developed in the Yuam river basin in the reservoir area (valley with 200 to 300 m at high water level) and a steeply sloped topography is presented. The Pon river coming down from Khun Yuam Village merges with the main stream at a point 7 km upstream of the projected dam site.

The geology comprising the reservoir area, is considered as a result of the surface reconnaissance made at a partial stretch of the Yuam river to be alternating beds of shale and sandstone with shale dominating. Outcrops along the river are weathered and brittle. The strikes and dips of the formations are N10° - 40°E and 30° - 50°SE. On estimating the geology of the reservoir by photogeological interpretations, the mountain body of EL. 631 m located 5 km to the north of the dam site has a steep conical configuration differing from the surrounding topography, and is thought to be an intrusive rock body. Further, the area to the north 2 km from the above point has a complex development of small gullies crossing perpendicularly with the river, and is estimated to consist of limestone. Places where surface deposits consisting of terrace deposits and talus deposits are widely distributed are not seen.

Regarding lineaments in the surroundings of the reservoir, according to photogeological interpretations, there are several at the west side (right-bank side) of the reservoir which extend in the north-south direction and have comparatively good continuity, although a part is in echelon form. There is also a lineament seen along Pa Lao Gully at the east side of the upstream area of the reservoir.

With regard to watertightness of the reservoir, judging by the results of a surface reconnaissance and photogeological interpretations, limestone estiamted to be distributed in the upstream area is at above EL. 400 m and higher up than high water level of

380 m so that it is considered not to be a problem. Furthermore, the alternating beds of sandstone and shale thought to be widely distributed in the reservoir area also are not considered to be very much problems. However, the ridges at both sides of the dam site are problematic, especially, the left-bank side ridge is only about 200 m in width at high-water-level elevation of 380 m so that the permeability of this ground will be important in examining the watertightness of the reservoir.

Landslide configurations and areas of collapse are not seen at the reservoir slopes. Distributions of surface deposits are also thought to be small, and problems concerning destabilization of the reservoir are not recognizable.

2) Dam Site

Terrace deposits are developed at the both banks of the dam site and a flat terrace plane having a width of approximately 50 m is formed at each sides. The right-bank slope continuing from this terrace has a gradient of 30 to 35 deg. The left-bank side slope is steeply inclined at approximately 60 deg.

The geology in the vicinity of the dam site mainly consists of shale, but there is a part where sandstone is interbedded to form alternations.

Moreover, the distribution of massive and non-stratified siltstone is confirmed by core drilling.

The strike and dip of the formation are N40°E, 50°SE, diagonally intersecting the river and dippling toward the downstream side.

The shale at this site is weathered at a whole, has joints developed at spacings of 30 to 50 cm, is fissile from bedding plane, and is easily crushed. Collapses have occurred at the surface portion of weathered shale at the left abutment of the projected dam axis. On the other hand, the sandstone interbedded in part is very hard. Joints of strikes and dips N60° - 75°E, 90° are seen in the shale and sandstone.

The terrace deposit distributed widely over the flat area at the right-bank side consists of sand-gravel containing cobbles to boulders of 10 to 30 cm. Talus deposits are distributed at the slopes. The river deposits distributed along the Yuam river also consist of sand and gravel containing cobbles to boulders of 10 to 30 cm. It is thought the thicknesses of these surface deposits are not very large judging from the topography, but according to the results of core drilling executed at a flat plane of the right-bank side, the thickness of terrace deposits is 7.8 m. Faults have not been confirmed in the vicinity of the dam site in surface reconnaissances.

It is judged from the geological conditions of the ground surface and the results of drilling investigations including permeability tests that the foundation rock of this site has few problems as the foundation of a rockfill dam with regard to bearing capacity and permeability. However, drilling has not been performed on parts of high elevation at both abutments, and it will be necessary, hereafter, to grasp the bedrock condition at parts of high elevation. Especially, since the ridge at the left-bank of high-water level elevation is thin at about 200 m, it will be necessary for investigations to be made on the need for water cut-off treatment.

3.4.5 Nam Mae Rit

1) The Rit river upstream of the dam site meanders down repeatedly changing its course between the NW-SE direciton which is harmonious with the geological structure of the surroundings and a direction which is orthogonal to the above. The tributaries which feed the Rit river mostly flow in a direction along that of the geological structure. The valleys in the reservoir area make up a topography of steep V-shaped gorges, and almost no terrace land-forms can be seen.

   To estimate the geology comprising the reservoir area based on the results of photogeological interpretations and existing literature and data, it is conceivable that shale, the alternating beds of sandstone and shale, limestone, and granite are distributed in the reservoir area. Out of these, those that can be discerned comparatively distinctly in photogeological interpretations are the limestone and the granite. The former is thought to be widely distributed extending north-south east of the confluence between the Rit river and the Hong river approximately 6 km upstream from the dam site. Scattered sinkholes are seen at elevations of 1,100 to 1,200 m in this area. The latter granite is thought to be distributed at a mountain of steeply-sloped conical shape at the left-bank side of the Rit river approximately 4 km upstream from the dam site. It is thought that the shale and alternating beds of sandstone and shale are distributed at parts other than the two above.

Regarding watertightness of the reservoir, the distribution and nature of the limestone would be the problems, but from the facts that the large-scale rock body of limestone in the upstream area can be estimated to be distributed above high water level of 270 m, and moreover, the strike of the strata is orthogonal to the Rit river, there should be no problem about watertightness. On the other hand, the limestone distributed around 800 m upstream of the dam has numerous joints, and solution along the joints can be seen. This limestone formation is distributed in a direction orthogonal to the river similarly to the previously-mentioned upstream limestone body, while shale which can be expected to serve as an impervious zone is distributed at the downstream side, so that it is thought there will not be much of a problem concerning watertightness of the reservoir, but since this is close to the dam site, further detailed investigations concerning the distribution and properties of this limestone are necessary.

Lineaments found in the surrounding of the reservoir may be broadly divided into those along gullies and more or less in harmony with the strikes of the formations and those orthogonal to the above and running along the Rit River. These lineaments are short, being 2 to 4 km in length, and none is seen that would pose a problem in watertightness of the reservoir.

There is no place at the reservoir slopes where a landslide configurotion or area of collapse can be seen. The topography is rugged, but slopes are mostly stable, and there should be no problem about stability of reservoir slopes.

2) Dam Site

The abutments of the dam site are sloped at 40 - 50 deg at the right-bank side and 30 - 40 deg at the left-bank side.

Although at the left-bank side there are parts above about 40 m from the river bed that become slopped slightly gradually at 20 to 30 deg, as a whole the valley is in the form of a steep V-shape.

The geology in the vicinity of the dam site consists of chert, thin-layered alternations of chert and limestone, limestone, and shale.

These formations are affected by thermal metamorphism with the intrusion of the granite, and the shale is converted to cordierite hornfels.

The strikes of the formations are approximately NW-SE and the dips are 60 - 70°E. The abovementioned formations are distributed in band-like forms roughly parallel to the projected dam axis. Chert is distributed downstream of the dam site in a width of approximately 400 m and comprises a bedrock which is more or less fresh and hard, but there are irregular joints developed. Bedding with microfolding is observed in this formation with strike and dip N-S, 70°E. The thin-layered alternations of chert and limestone are located approximately on the projected dam axis at the right-bank side. The thicknesses of individual beds are 3 to 5 cm, with the two rocks in tight contact and hard, but the limestone parts show a trend of being subject to solution and forming depressions in relation to the chert. There is a part of this formation where joints are developed in the N70°W, 80°N direction at spacings of approximately 50 cm, and loosening has been produced at the surface portion. Limestone is distributed in widths of approximately 200 to 250 m centered at about 500 m downstream of the dam and about 800 m upstream. Joints at spacings of approximately 50 cm are developed in this rock, and some solution is recognized along the joints, but large-scale caves are not found in surface reconnaissances. The shale is widely distributed at the left-bank side and upstream of the dam site, while downstream, it is only found interbedded between the beforementioned chert and alternating beds of chert and limestone. Outcrops of this rock along the river are more or less fresh and hard. However, at outcrops along the road at the right-bank side immediately upstream of the projected dam axis, joints of N60° - 70°W, 40° - 70°S are developed, and loosening can be seen along these joints.

The surface deposits overlying the abovementioned bedrocks are terrace deposits, river deposits, and talus deposits. None of these deposits is widely distributed. The terrace deposits consist of sand and gravel with gravel of particle size 5 to 15 cm and intermixture of silt, the river deposits are sand-gravel containing a large number of subrounded gravels 30 cm in diameter, and the talus deposits consist of silt and clay mixed with hard gravels.

Faults have not been found in the vicinity of the dam site according to surface reconnaissances.

From the geological conditions of the ground surface and results of drilling investigations including permeability tests, the foundation rock and river-bed portion of this site consist of bedrock posing no problems regarding both bearing capacity and permeability, but the abutments at both sides are seen to be weathered to great depths, indicating that permeability will be comparatively high. Particularly, there is a fault zone at the left-bank abutment and deterioration is seen to reach deep inside. Consequently, with regard to this site, it will be necessary for thorough consideration to be given to foundation treatment at both abutments.

3.4.6 Upper Mae Rit 2a

This project is planned at the upstream most part of the Rit river and consists of an intake dam, power tunnel, and powerhouse. However, there was no accessibility to the projected structure sites and a field reconnaissance could not be made. Therefore, the study on the topographical and geological conditions of this project site was made based on 1:50,000 topographic maps and aerial photographs.

The longitudinal gradient of the river is steep over the entire project area while slopes at both banks also form steeply-shaped valleys.

Numerous sinkholes are seen scattered at elevations of 800 to 1,100 m on the top of the mountain body at the right-bank side of the Rit river and it is assumed that limestone is distributed there. At the mountain at the south side of roughly the projected powerhouse site presents a massive mountain mass differing from the topography of the surroundings and it is estimated that granite is distributed.

The problem about this project is that there may be springing of water during tunnel excavation and leakage from the reservoir since it is thought limestone is widely distributed at the intake dam and power tunnel route. Consequently, it will be necessary hereafter to investigate the properties and distribution of this limestone, especially the existence of large-scale caves that would be the causes of leakage, and the condition of existence of groundwater in the limestone.

3.4.7 Further Investigation Works

Geological conditions and engineering geological problems of each dam site are described in the paragraph 3.4.1 to 3.4.6.

Nam Mae Ngao No.2 dam site is considered to be most promissing among the above mentioned six dam sites. Therefore, further geological investigation works for the Nam Mae Ngao No. 2 dam site are recommended as follows;

1) Reservoir

- Surface geological investigation
  to grasp the distribution and the properties of limestone, hydrogeological conditions and stabilities of slopes in the reservoir area and to confirm the results of aerophoto interpretation which support the supposition that the posibility of leakage from the reservoir is small.

2) Dam site

- ° Surface geological investigation
  to confirm the detailed geological structure and distribution of limestone around the dam site.

- ° Drilling
  The contents, locations and quantities are indicated in Fig. 3-5 and Table 3-2.

3.5 Construction Materials

Regarding construction materials, studies were made with emphasis on selection of prospective areas for obtaining impervious core materials and rock materials concerning Nam Mae Ngao No. 2, Upper Mae Yuam 1, Upper Mae Yuam 2 and Nam Mae Rit projected sites.

Selection of these prospective areas was made mainly based on photo-geological interpretations. Further, confirmations were made of locations where samples were collected for impervious core materials in surface geological reconnaissances, and sample collection and laboratory tests were executed by EGAT.

The results of material tests are shown in Table 3.3-1 - 4.

3.5.1 Impervious Core Materials

1) Nam Mae Ngao No. 2

The gradually-sloped parts at the left bank approximately 500 m upstream of the dam site and approximately 400 m downstream were selected as candidate borrow areas.

The results of the surface geological reconnaissances revealed that materials distributed in these areas are weathered residual soil and talus deposits of the alternating beds of sandstone and shale.

At both sites, fourteen test pits of 1.8 m to 6.3 m in depth, totalling 55.0 m length, were digged (the location of test pits is shown in Fig. 3-11), and following material tests were carried out on samples collected.

Test Items	Quantity		Total
	Upstream Site	Downstream Site	
Water Content	11	11	22
Specific Gravity	11	11	22
Atterberg Limits	11	11	22
Gradation	11	11	22
Compaction	10	11	21
Permeability	2	1	3

The soil samples from 14 test pits can be generally classified as silty GRAVEL (GM) or fine sand with a varying amount of admixtures of medium to high plastic silt and clay (SM, ML, MH).

2) Upper Mae Yuam 1

The gently-sloped area spread out at the right-bank side of the Yuam River 200 to 500 m downstream of the dam site was selected as candidate borrow area.

The results of the surface geological reconnaissances revealed that materials distributed in this area are talus deposits with clay to silt with slight mixture of gravel and terrace deposits of sand-gravel containing a large amount of cobbles 5 to 10 cm in diameter.

At this site, twelve test pits of 2.0 m to 9.0 m in depth, totalling 57.0 m length, were digged (the location of test pits is shown in Fig. 3-12), and following material tests were carried out on sample collected.

The soil samples from 12 test pits can be generally classified as silty GRAVEL (GM) or sand with a varying amount of admixtures of low to medium plastic silt and clay (SM, SC).

Test Items	Quantity
Water Content	25
Specific Gravity	25
Atterberg Limits	25
Gradation	25
Compaction	15
Permeability	-

3) Upper Mae Yuam 2

The gradual slopes at the both banks immediately upstream of the dam site and at left bank 0.5 km downstream were selected as candidate borrow area.

The results of the surface geological reconnaissances revealed that materials distributed in these areas are lateritic weathered residnal soil, talus deposits and terrace deposits.

At these sites, twelve test pits of 1.6 m to 6.0 m in depth, totalling 55.2 m length, were digged (the location of test pits is shown in Fig. 3-12), and following materials tests were carried out on sample collected.

Test Items	Quantity		Total
	Upstream Site	Downstream Site	
Water Content	20	4	24
Specific Gravity	20	4	24
Atterberg Limits	20	4	24
Gradation	20	4	24
Compaction	20	4	24
Permeability	2	1	3

The soil samples from 12 test pits can be generally classified as silty GRAVEL (GM) or sand with a varying amount of admixtures of medium to high plastic silt and clay (SM, ML).

4) Nam Mae Rit

Places that would be candidate borrow areas are the ridge-like gentle slopes approximately 500 m downstream from the dam site on the right-bank side and 800 m downstream on the left-bank side.

The results of the surface geological reconnaissances revealed that materials distributed in those areas are lateritic weathered residual soil and talus deposits with high content of fine grained materials.

Thirteen test pits of 1.2 m to 7.4 m in depth, totalling 45.1 m length, were digged including gradual slopes immediately upstream from dam site and 1.5 km upstream on left-bank side other than above two sites (the location of test pits is shown in Fig. 3-12), and following material tests were carried out on sample collected.

Test Items	Quantity				Total
	Immediately upstream	1.5 km upstream	0.5 km downstream	0.8 km downstream	
Water Content	8	4	9	7	28
Specific Gravity	8	4	9	7	28
Atterberg Limits	8	4	9	7	28
Gradation	8	4	9	7	28
Compaction	7	-	8	6	21
Permeability	-	-	-	-	-

The soil samples from 13 test pits can be generally classified as silty GRAVEL (GM) or high plastic elastic SILT (MH).

3.5.2 Rock Materials

Selection of prospective areas for obtaining rock materials was made based on photogeological interpretations (see Fig. 3-11 and Fig. 3-12).

At Nam Mae Ngao No. 2 project site, the ridge protruding westward at the right bank 500 m upstream from the dam site in the reservoir area, and the ridge at the left bank 1,200 m upstream from the dam site can be cited as candidate quarry sites.

The geology of these sites consists mainly of the alternating beds of sandstone and shale.

Since the sandstone and shale alternations are weathered at many places so far as seen from the ground surface, and further detailed investigations are necessary regarding hardness and conditions of joints.

Other than above two sites, the limestone rock body distributed at higher part than EL. 400 m at approximately 3 km west from dam site can be cited as candidate site.

At Upper Mae Yuam 1 project site, geology where hardness and particle-diameter conditions might be satisfied could not be found in the surface reconnaissances made this time, and it was not possible to select a candidate site. However, the hard conglomerate seen in the form of boulders at the right-bank side of the dam site and the limestone interbedded with the alternating beds of sandstone and shale are thought can be utilized as rock material, and it will be necessary to investigate the site of distribution further.

At Upper Mae Yuam 2 project site, there are only soft and brittle alternating beds of sandstone and shale in the vicinity of the dam site. Seeking a candidate quarry site in the upstream area, a mountain 7 km upstream estimated to be an intrusive rock body in photogeological interpretations can be cited. It will be necessary hereafter to grasp the geological properties and distribution of this rock mass. It will also be necessary to investigate further whether rock materials can be obtained at a location closer to the dam site.

At Nam Mae Rit project site, the granite rock body estimated to be distributed at the left-bank side of the Rit river approximately 4 km upstream from the dam site may be cited from the results of photo-geological interpretations.

It will be necessary hereafter to grasp geological properties and distribution of this rock mass. It will also be necessary to investigate further whether rock materials can be obtained at a location closer to the dam site.

Table 3–3–1 Results of Soil Test (Nam Mae Ngao No. 2)

Location	Sample No.	Depth (m)	Classification of Soils by Unified System	Specific Gravity	Natural Water Content (%)	Atterberg Limits LL (%)	Atterberg Limits PI (%)	Gradation Analysis -19.0 mm (%)	-4.76 mm (%)	-2.0 mm (%)	-0.42 mm (%)	-0.074 mm (%)	-0.01 mm (%)	-0.002 mm (%)	Compaction Maximum Dry Density (t/m³)	Compaction Optimum Water Content (%)	Permeability Coefficient of Permeability (cm/sec)	Permeability Molded Water Content (%)
Upstream site	NG-2	0.4 - 5.9	ML	2.68	11.21	37.75	12.47	100.0	98.46	95.40	81.33	52.13	39.98	30.15	1.787	15.4	-	-
	NG-4	0.5 - 4.1	MH	2.73	19.96	54.10	19.45	74.77	61.25	57.63	54.79	50.29	38.75	25.15	1.580	23.2	-	-
	NG-6	0.5 - 6.5	SM	2.63	22.11	30.81	6.58	100.0	99.89	98.96	89.34	47.98	34.15	22.23	1.757	17.0	-	-
	NG-8	0.4 - 2.7	MH	2.74	14.27	53.70	22.68	100.0	91.51	81.46	74.08	63.78	52.50	40.00	1.675	21.0	-	-
	NG-10	0.5 - 2.2	GM	2.75	4.37	54.20	22.79	86.54	68.65	62.23	58.56	50.38	39.98	30.00	1.654	21.2	-	-
	NG-12	0.4 - 1.8	SM	2.71	15.65	41.61	13.67	100.0	74.51	65.42	61.10	45.31	34.10	22.50	1.722	17.8	-	-
	"	1.8 - 6.3	ML	2.68	12.04	27.40	3.51	100.0	96.74	93.73	89.61	52.80	36.00	18.17	1.710	17.2	-	-
	"	0.4 - 6.3	SM	2.70	3.82	34.75	9.63	97.57	83.62	77.49	71.98	47.70	37.10	22.75	-	-	-	-
	NG-14	0.6 - 3.6	SM	2.67	1.45	29.00	4.60	96.98	78.32	68.44	57.78	41.06	27.50	17.52	1.775	17.0	-	-
	NG-2,4,6,8		SM	2.70	13.75	47.70	17.76	84.04	66.12	59.19	49.47	35.85	26.25	18.85	1.790	15.4	2.75×10^{-8}	17.8
	NG-10,12,14		GM	2.70	6.63	30.50	7.15	71.68	53.97	48.99	45.85	31.12	22.30	13.50	1.775	15.6	1.20×10^{-7}	18.1
Downstream site	NG-1	0.3 - 1.8	SM	2.69	10.88	45.18	15.27	90.62	66.83	45.96	34.40	28.87	24.15	20.00	1.739	17.6	-	-
	NG-3	0.5 - 4.9	ML	2.67	18.78	45.10	16.43	100.0	98.19	95.30	87.87	62.63	49.20	37.60	1.686	18.3	-	-
	NG-5	0.5 - 4.5	SM	2.68	15.89	33.30	6.66	100.0	94.08	88.74	80.37	44.16	32.50	20.00	1.765	16.5	-	-
	NG-7	0.4 - 2.9	GM	2.74	18.39	51.40	21.31	82.23	60.73	50.63	44.66	34.76	28.00	22.35	1.770	16.5	-	-
	"	2.9 - 3.8	GC	2.71	11.16	39.80	15.25	74.31	54.58	48.93	45.50	33.19	24.15	15.96	1.806	15.1	-	-
	"	0.4 - 3.8	GM	2.72	14.78	42.60	15.33	84.53	59.24	50.14	44.31	30.21	21.90	15.16	1.768	15.2	-	-
	NG-9	0.4 - 3.3	MH	2.72	16.23	54.65	25.19	98.64	85.18	76.51	68.94	59.70	48.85	37.65	1.613	22.3	-	-
	NG-11	0.5 - 3.1	GM	2.69	11.46	50.45	22.32	70.13	39.53	27.35	19.97	17.82	15.00	11.75	1.757	16.4	-	-
	NG-13	0.4 - 2.3	MH	2.69	19.81	59.00	21.33	95.83	68.71	60.00	56.66	54.10	47.00	38.10	1.535	26.5	-	-
	NG-1,3,5,7		SM	2.69	7.74	44.30	15.47	87.61	73.83	66.72	57.06	37.12	27.75	20.90	1.793	16.3	3.10×10^{-8}	17.7
	NG-9,11,13		MH	2.71	17.98	57.70	25.52	91.44	72.26	62.63	55.73	50.28	43.75	35.00	1.680	19.6	3.10×10^{-8}	20.6

Table 3–3–2 Results of Soil Test (Upper Mae Yuam 1)

	Sample No.	Depth (m)	Classification of Soils by Unified System	Specific Gravity	Natural Water Content (%)	Atterberg Limits LL (%)	Atterberg Limits PI (%)	Gradation Analysis -19.0 mm (%)	-4.76 mm (%)	-2.0 mm (%)	-0.42 mm (%)	-0.074 mm (%)	-0.01 mm (%)	-0.002 mm (%)	Compaction Maximum Dry Density (t/m³)	Compaction Optimum Water Content (%)	Permeability Coefficient of Permeability (cm/sec)	Permeability Molded Water Content (%)
Downstream of dam site	Y1-2	0.6 - 7.0	SM	2.68	15.94	47.80	18.39	90.09	69.34	51.43	33.42	28.27	25.00	17.35	-	-	-	-
	"	7.0 - 9.0	GM	2.66	7.75	39.90	9.62	83.35	65.35	53.19	40.92	33.50	26.90	17.30	-	-	-	-
	"	0.6 - 9.0	GM	2.72	5.99	40.32	9.81	95.67	63.65	51.32	42.76	38.87	32.18	22.05	1.578	21.7	-	-
	Y1-4	0.5 - 7.0	GM	2.80	19.65	47.50	17.08	86.39	52.44	40.00	29.74	24.07	19.98	13.70	1.693	17.2	-	-
	Y1-6	0.3 - 3.1	GM	2.72	12.05	39.50	13.43	57.74	24.86	17.04	11.69	7.32	6.15	4.10	-	-	-	-
	"	3.1 - 5.1	GM	2.72	15.05	52.30	21.05	89.65	58.50	46.09	31.84	25.36	22.20	16.25	-	-	-	-
	"	0.3 - 5.1	GM	2.71	16.91	48.45	19.85	82.59	47.29	36.72	27.72	23.97	20.00	15.05	1.685	19.3	-	-
	Y1-8	0.7 - 4.6	GM	2.67	9.31	41.25	15.40	89.36	67.30	56.52	48.94	38.61	31.25	23.10	1.705	19.6	-	-
	Y1-10	0.4 - 2.0	ML	2.66	11.06	41.40	15.09	100.0	93.80	86.50	74.76	66.00	54.00	36.15	1.684	20.4	-	-
	Y1-12	0.5 - 2.0	SC	2.66	7.55	35.80	13.87	96.24	80.93	59.76	42.19	36.13	30.05	21.15	1.810	15.4	-	-
	Y1-14	0.5 - 3.9	SM	2.67	11.46	28.75	5.76	100.0	92.85	87.44	71.35	44.23	32.50	21.50	1.825	14.5	-	-
	Y1-16	0.4 - 3.0	SM	2.67	8.57	27.80	4.74	93.30	84.93	81.58	70.50	39.05	29.99	19.80	-	-	-	-
	"	3.0 - 7.1	SC	2.66	10.25	30.50	8.60	95.82	91.52	88.44	73.43	33.71	21.20	10.26	-	-	-	-
	"	0.4 - 7.1	SC	2.67	8.20	29.00	7.90	92.11	85.60	82.59	70.19	36.99	26.25	14.89	1.790	15.6	-	-
	Y1-18	0.4 - 2.7	CL	2.68	12.52	39.20	16.72	100.0	99.33	98.17	85.19	54.29	41.00	35.05	-	-	-	-
	"	2.7 - 4.0	CL	2.68	13.39	40.70	18.40	100.0	97.34	94.73	82.29	52.70	37.80	30.00	-	-	-	-
	"	0.4 - 4.0	CL	2.67	12.67	38.00	15.92	100.0	98.41	96.41	83.09	52.93	37.75	32.45	1.788	16.1	-	-
	Y1-20	0.4 - 5.0	ML	2.69	15.64	31.70	8.25	-	100.0	99.76	94.28	54.03	37.60	21.66	1.745	17.1	-	-
	Y1-22	0.4 - 4.1	GM	2.64	7.89	36.80	10.90	83.58	66.32	63.07	51.04	35.54	21.00	9.85	1.738	16.9	-	-
	Y1-24	0.3 - 2.5	CL	2.71	11.22	49.60	24.46	100.0	99.70	97.72	86.43	64.75	51.50	44.95	-	-	-	-
	"	2.5 - 3.2	SM	2.69	9.20	27.70	6.50	100.0	99.91	97.62	83.25	46.74	37.75	20.05	-	-	-	-
	"	0.3 - 3.2	CL	2.68	9.66	28.80	7.29	100.0	99.64	97.32	84.27	53.76	39.85	27.70	1.819	14.7	-	-
	Y1-2,4,6,8		GM	2.74	9.92	39.20	10.93	98.97	63.86	52.78	42.85	35.25	26.25	17.65	1.711	17.0	-	-
	Y1-10,12,14,16		SM	2.69	8.74	28.90	6.57	90.72	83.67	76.06	62.77	37.94	28.00	17.40	1.825	14.4	-	-
	Y1-18,20,22,24		ML	2.68	12.47	35.60	12.00	100.0	98.07	96.16	84.47	55.09	39.50	25.30	1.785	15.8	-	-

Table 3–3–3 Results of Soil Test (Upper Mae Yuam 2)

Location	Sample No.	Depth (m)	Classification of Soils by Unified System	Specific Gravity	Natural Water Content (%)	Atterberg Limits LL (%)	Atterberg Limits PI (%)	Gradation Analysis -19.0 mm (%)	-4.76 mm (%)	-2.0 mm (%)	-0.42 mm (%)	-0.074 mm (%)	-0.01 mm (%)	-0.002 mm (%)	Compaction Maximum Dry Density (t/m^3)	Optimum Water Content (%)	Permeability Coefficient of Permeability (cm/sec)	Molded Water Content (%)
Upstream site	Y2-2	0.4 - 3.0	SM	2.66	1.09	23.10	5.57	100.0	98.76	97.23	84.21	40.72	30.10	22.35	1.913	12.2	-	-
	"	3.0 - 6.0	SM	2.71	3.77	21.90	1.47	88.44	61.27	51.10	37.40	14.92	11.00	7.46	2.050	9.0	-	-
	"	0.4 - 6.0	GM	2.67	7.28	21.13	2.26	72.27	55.88	50.11	39.73	16.32	11.70	7.81	2.050	9.5	-	-
	Y2-4	0.4 - 4.0	GM	2.74	10.37	45.70	17.68	75.01	62.12	52.02	43.83	39.28	32.60	24.97	1.765	18.0	-	-
	Y2-6	0.6 - 5.2	SM	2.76	6.17	51.40	20.80	90.58	78.89	65.78	51.69	46.48	40.00	33.75	1.736	19.0	-	-
	Y2-10	0.6 - 4.6	ML	2.68	7.60	28.50	8.06	100.0	99.65	99.24	93.94	53.36	34.98	26.80	1.881	13.1	-	-
	"	4.6 - 5.4	SM	2.66	5.43	24.67	4.30	100.0	99.10	97.28	86.59	38.99	26.15	19.00	1.903	12.8	-	-
	"	0.6 - 5.4	SM	2.67	5.55	26.85	6.66	100.0	98.95	97.61	89.49	43.08	29.10	22.00	1.882	11.3	-	-
	Y2-12	0.5 - 4.0	MH	2.70	12.43	57.60	24.84	99.87	94.12	77.07	61.34	51.84	47.35	37.50	1.674	20.0	-	-
	Y2-14	0.4 - 1.6	ML	2.70	10.23	35.90	12.31	100.0	98.36	97.09	88.33	79.23	62.10	38.95	1.775	16.4	-	-
	"	1.6 - 3.0	CL	2.73	11.79	37.10	13.12	96.5	88.84	84.39	77.48	72.66	56.00	37.15	1.766	17.1	-	-
	"	0.4 - 3.0	ML	2.71	6.88	39.50	13.30	90.02	81.32	77.12	67.66	56.57	45.50	30.10	1.758	16.2		
		0.4 - 2.8	GM	2.79	20.91	52.80	20.70	76.88	51.44	41.54	35.84	34.52	29.97	22.45	1.587	24.15	-	-
	Y2-16	2.8 - 4.0	GM	2.73	18.25	46.70	16.78	83.50	54.63	45.33	39.43	38.11	32.80	22.65	1.646	21.6	-	-
	"	0.4 - 4.0	GM	2.73	18.43	57.20	22.58	77.98	43.43	31.68	22.28	18.69	16.50	12.80	1.615	22.0	-	-
	Y2-18	1.1 - 5.1	MH	2.71	17.27	56.90	22.91	100.0	89.15	69.61	57.33	49.13	44.00	33.10	1.635	22.8	-	-
	Y2-20	0.6 - 2.5	CL	2.67	9.68	33.20	13.91	100.0	95.77	92.79	89.86	70.18	47.45	33.0	1.832	14.4	-	-
	"	2.5 - 3.7	CL	2.66	10.45	31.35	12.38	100.0	99.03	98.61	97.06	72.82	52.45	37.75	1.841	14.0	-	-
	"	0.6 - 3.7	CL	2.69	9.43	37.30	14.93	100.0	98.56	96.36	92.91	64.34	47.10	34.15	1.810	15.7	-	-
	Y2-2,4,6		SM	2.73	5.36	38.58	11.61	85.63	74.99	63.61	51.01	39.74	34.99	27.50	1.857	15.4	$2.30x10^{-8}$	18.0
	Y2-10,12,14,16,18,20		ML	2.70	12.15	35.55	10.82	87.42	76.54	69.36	61.48	49.39	37.95	27.50	1.795	16.6	$3.20x10^{-8}$	18.6
Downstream site	Y2-1	0.4 - 3.0	SM	2.79	7.29	47.60	18.92	100.0	97.95	96.38	84.03	37.30	27.30	21.10	1.734	19.4	-	-
	Y2-3	0.6 - 4.8	MH	2.77	8.08	56.90	24.55	94.82	76.88	64.48	61.36	59.65	54.10	40.00	1.600	21.6	-	-
	Y2-5	0.5 - 2.4	GM	2.78	6.07	41.10	15.11	91.33	57.60	44.61	38.54	36.70	30.00	22.10	1.756	18.3	-	-
	Y2-1,3,5		GM	2.74	11.56	46.60	18.72	84.26	47.36	34.55	26.34	23.32	19.25	14.28	1.749	19.1	$3.50x10^{-7}$	21.0

Table 3-3-4 Results of Soil Test (Nam Mae Rit)

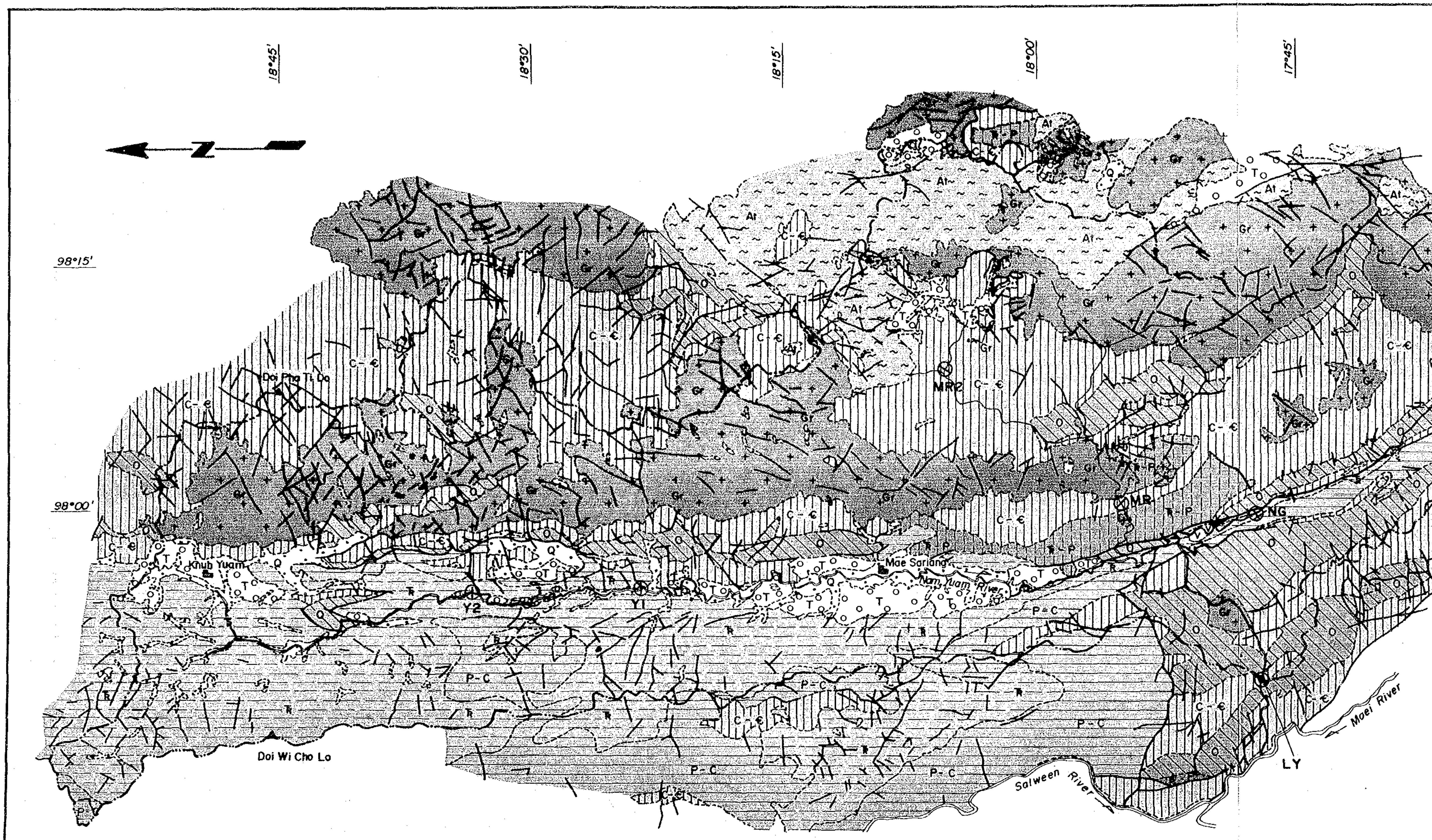
(1/2)

Location	Sample No.	Depth (m)	Classification of Soils by Unified System	Specific Gravity	Natural Water Content (%)	Atterberg Limits		Gradation Analysis							Compaction		Permeability	
						LL (%)	PI (%)	-19.0 mm (%)	-4.76 mm (%)	-2.0 mm (%)	-0.42 mm (%)	-0.074 mm (%)	-0.01 mm (%)	-0.002 mm (%)	Maximum Dry Density (t/m^3)	Optimum Water Content (%)	Coefficient of Permeability (cm/sec)	Molded Water Content (%)
Immediately Upstream site	MR-2	0.4 - 1.5	GM	2.72	12.36	47.43	19.54	95.61	61.92	44.36	34.67	31.21	27.65	18.10	1.787	16.7	-	-
	"	1.5 - 3.1	MH	2.73	24.87	50.80	15.0	88.75	66.69	59.25	53.32	50.75	41.45	18.99	1.476	27.7	-	-
	"	0.4 - 3.1	GM	2.67	21.26	51.40	17.39	92.31	64.86	50.66	41.01	37.43	32.25	20.00	1.675	22.7	-	-
	MR-4	0.3 - 1.2	MH	2.69	23.00	65.20	29.85	99.08	89.12	80.16	72.12	67.66	63.85	43.05	1.505	26.5	-	-
	"	1.2 - 3.2	MH	2.70	23.22	49.60	15.41	95.03	81.61	69.75	55.42	49.09	37.90	20.05	1.525	26.2	-	-
	"	0.3 - 3.2	MH	2.70	23.54	52.56	18.30	95.15	84.74	73.62	60.08	52.92	43.85	22.25	1.527	25.9	-	-
	MR-6	0.4 - 1.5	GM	2.73	13.11	55.92	24.62	72.22	42.96	31.96	23.42	20.19	17.20	13.85	1.808	16.8	-	-
	MR-2,4,6		GM	2.63	13.71	54.00	20.57	83.65	60.86	49.95	41.33	37.68	31.75	19.18	1.622	20.0	2.2×10^{-8}	23.2
1.5Km Upstream site	MR-8	0.5 - 5.0	SM	2.66	10.31	43.70	14.49	100.0	99.81	95.78	51.88	26.31	21.75	14.95	-	-	-	-
	MR-10	0.4 - 3.2	SM	2.67	6.26	42.70	10.48	100.0	96.25	77.87	37.80	22.69	11.15	10.00	-	-	-	-
	MR-12	1.3 - 3.4	SM	2.63	8.12	34.40	6.24	100.0	98.88	96.05	75.48	32.20	22.60	14.12	-	-	-	-
	MR-8,10,12		SM	2.63	8.34	41.20	10.31	98.61	96.88	88.42	52.52	26.31	21.25	12.55	1.791	14.6	4.9×10^{-8}	16.0

Table 3–3–4 Results of Soil Test (Nam Mae Rit)

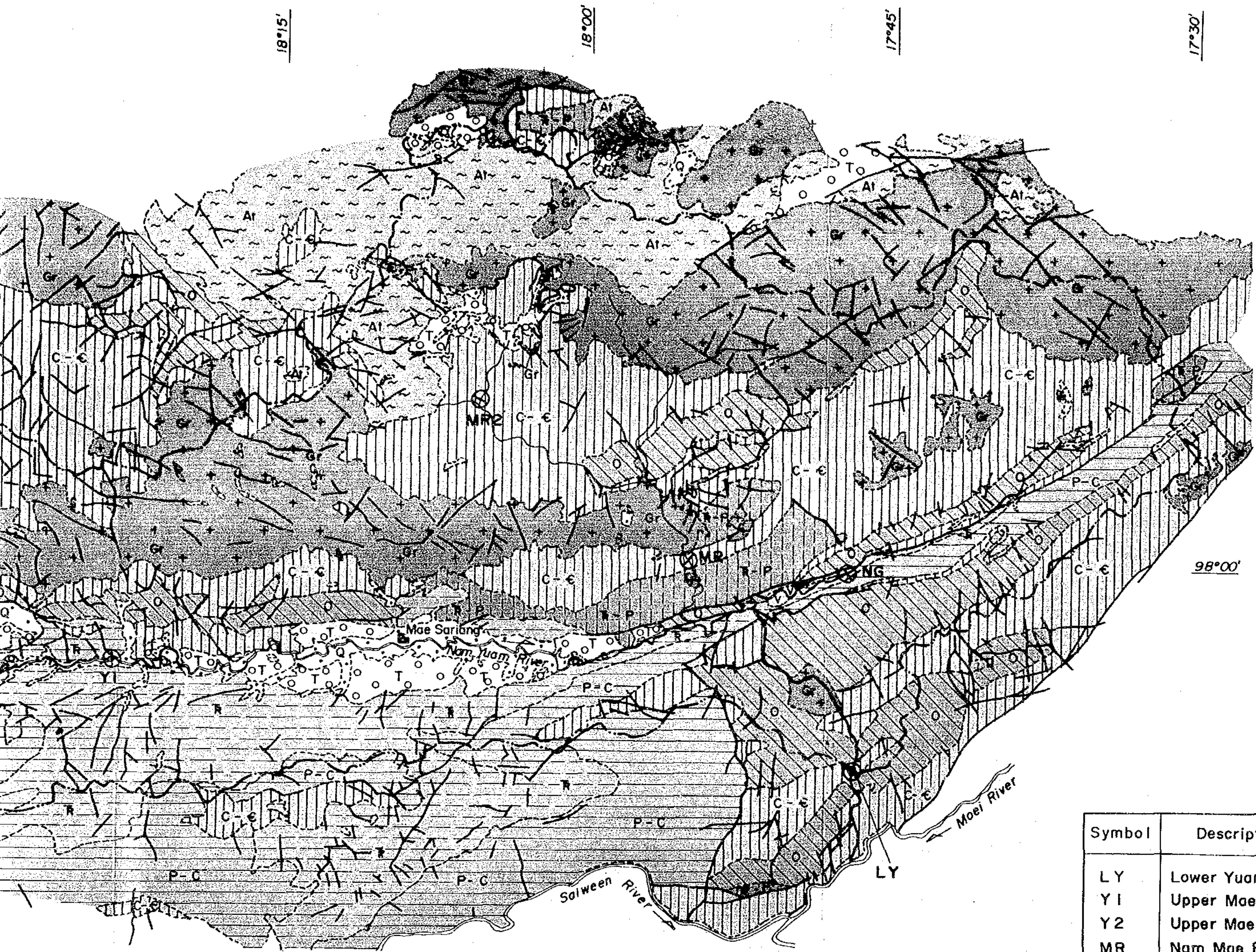
(2/2)

Location	Sample No.	Depth (m)	Classification of Soils by Unified System	Specific Gravity	Natural Water Content (%)	Atterberg Limits LL (%)	Atterberg Limits PI (%)	Gradation Analysis -19.0 mm (%)	-4.76 mm (%)	-2.0 mm (%)	-0.42 mm (%)	-0.074 mm (%)	-0.01 mm (%)	-0.002 mm (%)	Compaction Maximum Dry Density (t/m^3)	Compaction Optimum Water Content (%)	Permeability Coefficient of Permeability (cm/sec)	Permeability Molded Water Content (%)
0.5 Km Downstream site	MR-1	0.9 - 2.2	GM	2.72	6.52	48.65	17.27	86.30	56.25	42.02	32.05	28.02	23.20	15.08	1.722	17.0	-	-
	MR-3	0.2 - 4.2	MH	2.71	10.90	62.30	30.18	92.91	80.14	72.10	66.54	63.54	57.40	40.00	1.649	21.0	-	-
	MR-5	0.2 - 0.9	MH	2.76	9.48	58.35	25.70	98.90	92.96	88.20	83.99	80.66	72.60	52.05	1.598	22.2	-	-
	"	0.9 - 3.1	GM	2.72	5.96	51.80	22.59	85.21	54.32	43.36	37.02	34.24	29.00	21.00	1.802	16.6	-	-
	"	3.1 - 4.5	MH	2.74	16.82	53.50	19.81	99.12	93.09	85.21	75.71	71.09	61.10	36.00	1.612	22.5	-	-
	"	4.5 - 5.9	GM	2.76	13.09	49.10	19.00	83.44	57.82	41.70	28.82	23.68	18.30	13.00	1.787	16.3	-	-
	"	5.9 - 7.4	GM	2.75	11.85	45.20	18.64	95.21	63.23	44.45	30.12	24.51	13.25	12.50	1.832	15.2	-	-
	"	0.2 - 7.4	GM	2.74	11.91	49.60	19.78	62.13	41.02	32.77	26.76	24.51	20.00	15.00	1.774	17.1	-	-
	MR-1,3,5		GM	2.70	6.68	54.80	25.62	70.88	51.64	42.71	36.49	33.50	27.55	20.00	1.778	16.3	1.75×10^{-8}	18.50
0.8 Km Downstream site	MR-7	0.2 - 2.9	MH	2.76	17.82	57.50	21.46	97.86	91.13	78.40	67.20	61.98	55.10	44.00	1.622	23.6	-	-
	MR-9	0.2 - 1.7	SM	2.73	12.16	53.20	19.30	98.63	76.89	63.57	53.37	48.37	42.00	30.10	1.658	19.9	-	-
	"	1.7 - 5.0	GM	2.75	20.97	50.60	13.63	80.40	50.48	40.63	34.30	31.51	25.85	14.90	1.543	24.8	-	-
		0.2 - 5.0	GM	2.73	16.65	49.30	14.17	89.62	56.98	45.53	38.27	34.87	29.50	17.00	1.560	24.6	-	-
	MR-11	0.2 - 1.2	GM	2.77	6.07	51.10	21.36	92.72	60.31	45.82	35.70	31.50	27.55	23.10	1.782	16.35	-	-
	MR-13	0.2 - 2.8	MH	2.68	3.53	52.60	20.94	95.96	78.68	65.52	55.27	51.72	45.00	33.10	1.777	16.8	-	-
	MR-7,9,11,13		GM	2.75	7.47	52.70	19.66	87.14	65.96	53.57	43.17	38.25	30.05	22.45	1.705	18.8	2.6×10^{-8}	21.0



Symb
LY
Y1
Y2
MR
MR2
NG

Note : This map is compiled and simplified from Geological Map of Northern Thailand (1/250,000) prepared by German Geological Mission in 1981 and Geological Map of Thailand 「CHANGWAT CHIANG MAI」(1/250,000) prepared by ROYAL THAI Department of Mineral Resources in 1970.



LEGEND

Cenozoic	Quaternary	Q	Gravel, Sand
	Tertiary	T	Conglomerate, Sandstone, Shale
Mesozoic	Triassic	₸	Conglomerate, Shale, Sandstone, Limestone, Chert
	Triassic ~Permian	₸-P	Shale, Sandstone, Limestone
Paleozoic	Permian ~Carboniferous	P-C	Sandstone, Shale, Chert, Conglomerate, Limestone
	Ordovician	O	Limestone, Shale
	Carboniferous ~ Cambrian	C-Є	Shale, Chert, Limestone, Sandstone
		At	Anatexitic aureole of Paleozoic granite with relics of lower Paleozoic and Precambrian rocks
		Gr	Granite
		Ba	Basalt
			Geologic boundary
			Fault

0 — 20 km

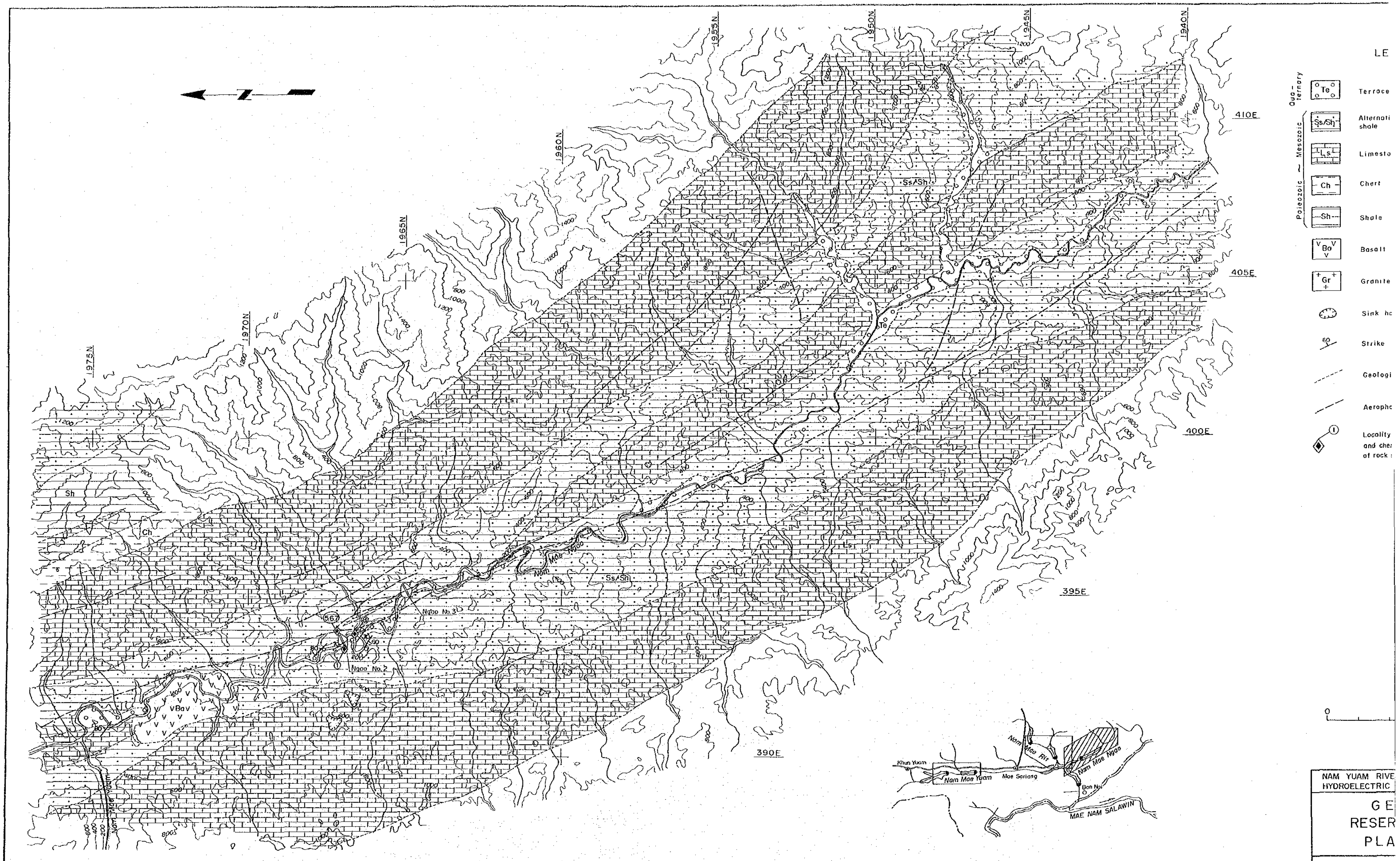
Symbol	Description
LY	Lower Yuam
Y1	Upper Mae Yuam 1
Y2	Upper Mae Yuam 2
MR	Nam Mae Rit
MR2	Upper Mae Rit 2a
NG	Nam Mae Ngao

s map is compiled and simplified from Geological Map of Northern Thailand (1/250,000) pared by German Geological Mission in 1981 and Geological Map of Thailand ⌜CHANGWAT ANG MAI⌟ (1/250,000) prepared by ROYAL THAI Department of Mineral Resources in 1970.

NAM YUAM RIVER BASIN HYDROELECTRIC DEVELOPMENT PROJECT

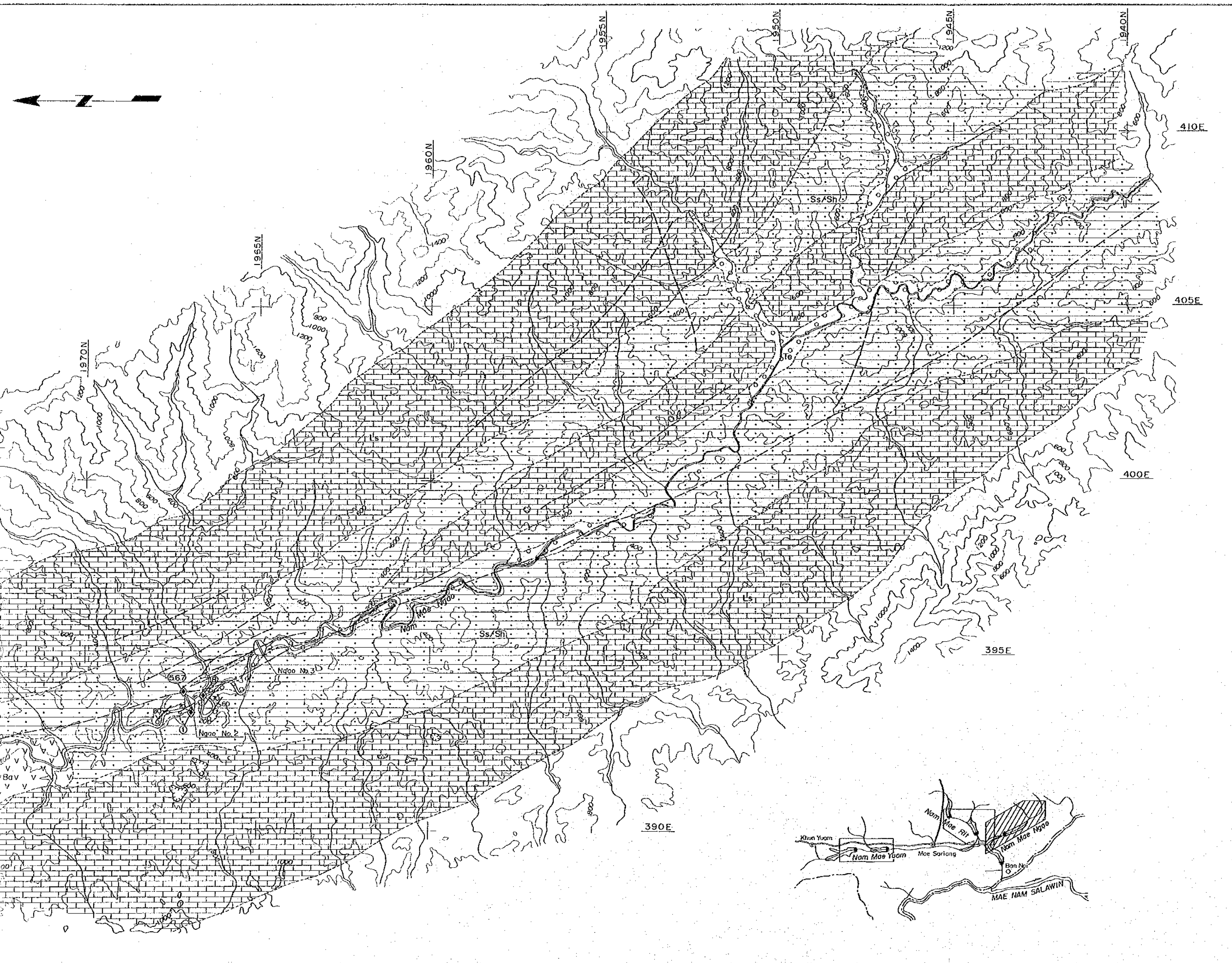
GEOLOGY
CATCHMENT AREA PLAN

Fig. 3–1



1975N
1970N
1965N
1960N
1955N
1950N
1945N
1940N
410E
405E
400E
395E
390E
Ss/Sh
Ls
Sh
Ch
VBav
Nam Mae Ngao
Ngao No.3
Ngao No.2
567
LE
Qua-ternary
Terrace
Alternati shale
Limesto
Chert
Shale
Basalt
Granite
Sink ho
Strike
Geologi
Aerophe
Locality and cher of rock
Paleozoic — Mesozoic
Khun Yuam
Nam Mae Yuam
Mae Sariang
Nam Mae Rit
Nam Mae Ngao
Ban Nu
MAE NAM SALAWIN
NAM YUAM RIVE
HYDROELECTRIC
GE
RESER
PLA

Fig. 3-2



LEGEND

Qua-ternary
- Te — Terrace deposit

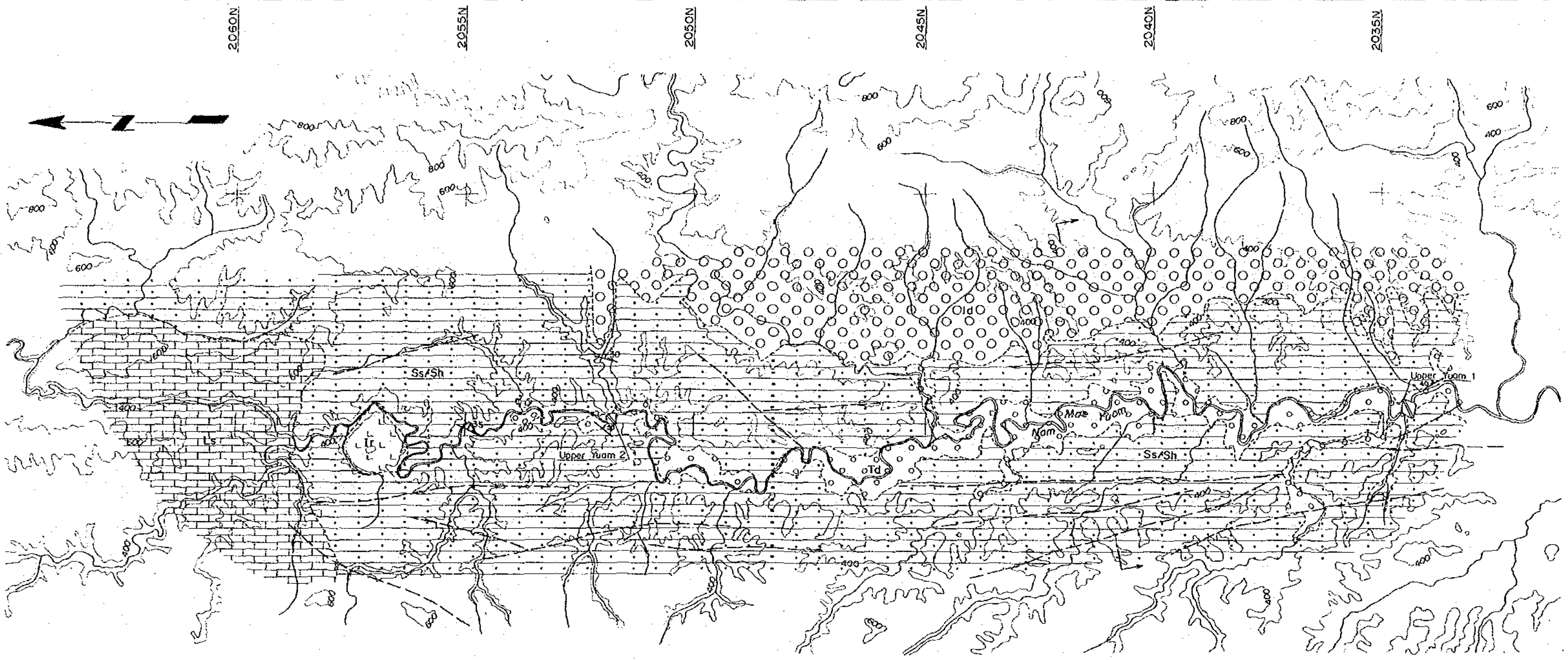
Paleozoic ~ Mesozoic
- Ss/Sh — Alternation of sandstone and shale
- Ls — Limestone
- Ch — Chert
- Sh — Shale

- Ba — Basalt
- Gr — Granite
- Sink hole
- Strike and dip of strata
- Geologic boundary
- Aerophoto lineament
- Locality for thin section and chemical analysis of rock samples

NAM YUAM RIVER BASIN
HYDROELECTRIC DEVELOPEMENT PROJECT

GEOLOGY
RESERVOIR AREA
PLAN (1-3)

Fig. 3–2



LEGEND

Tertiary ~Quaternary

Te — Terrace deposit

Td — Lake deposit

Paleozoic ~ Mesozoic

Ss/Sh — Alternation of sandstone and shale

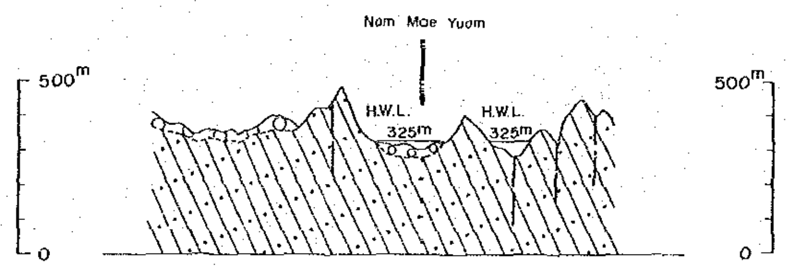
Ls — Limestone

Ir — Intrusive rock

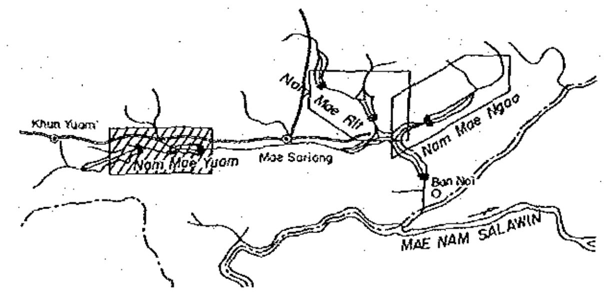
60 — Strike and dip of strata

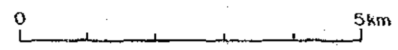
Geologic boundary

Aerophoto lineament



Note ; The geologic section is drawn on a different scale for vertical and horizontal.

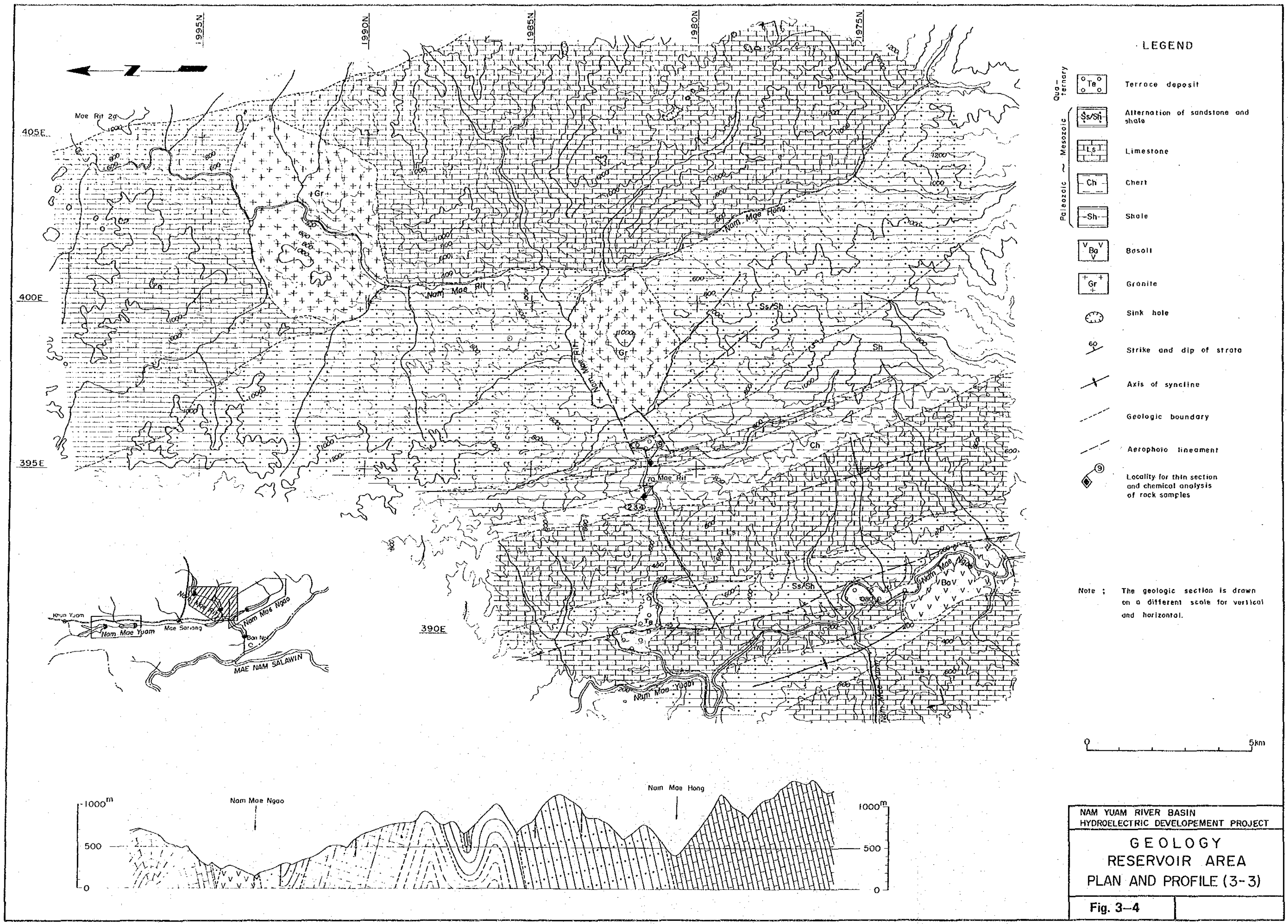




NAM YUAM RIVER BASIN
HYDROELECTRIC DEVELOPEMENT PROJECT

GEOLOGY
RESERVOIR AREA
PLAN AND PROFILE (2-3)

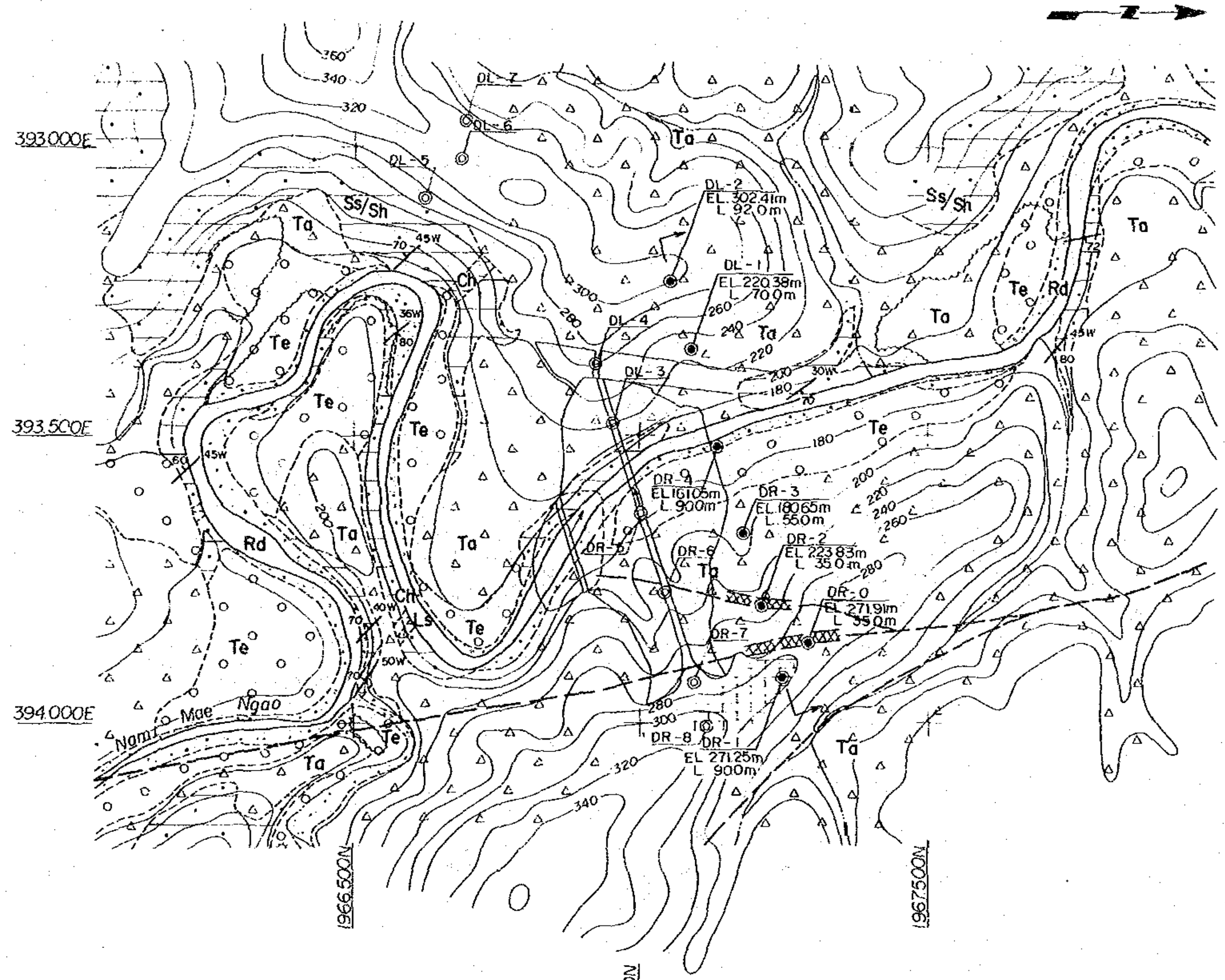
Fig. 3-3



NAM YUAM RIVER BASIN
HYDROELECTRIC DEVELOPEMENT PROJECT

GEOLOGY
RESERVOIR AREA
PLAN AND PROFILE (3-3)

Fig. 3–4



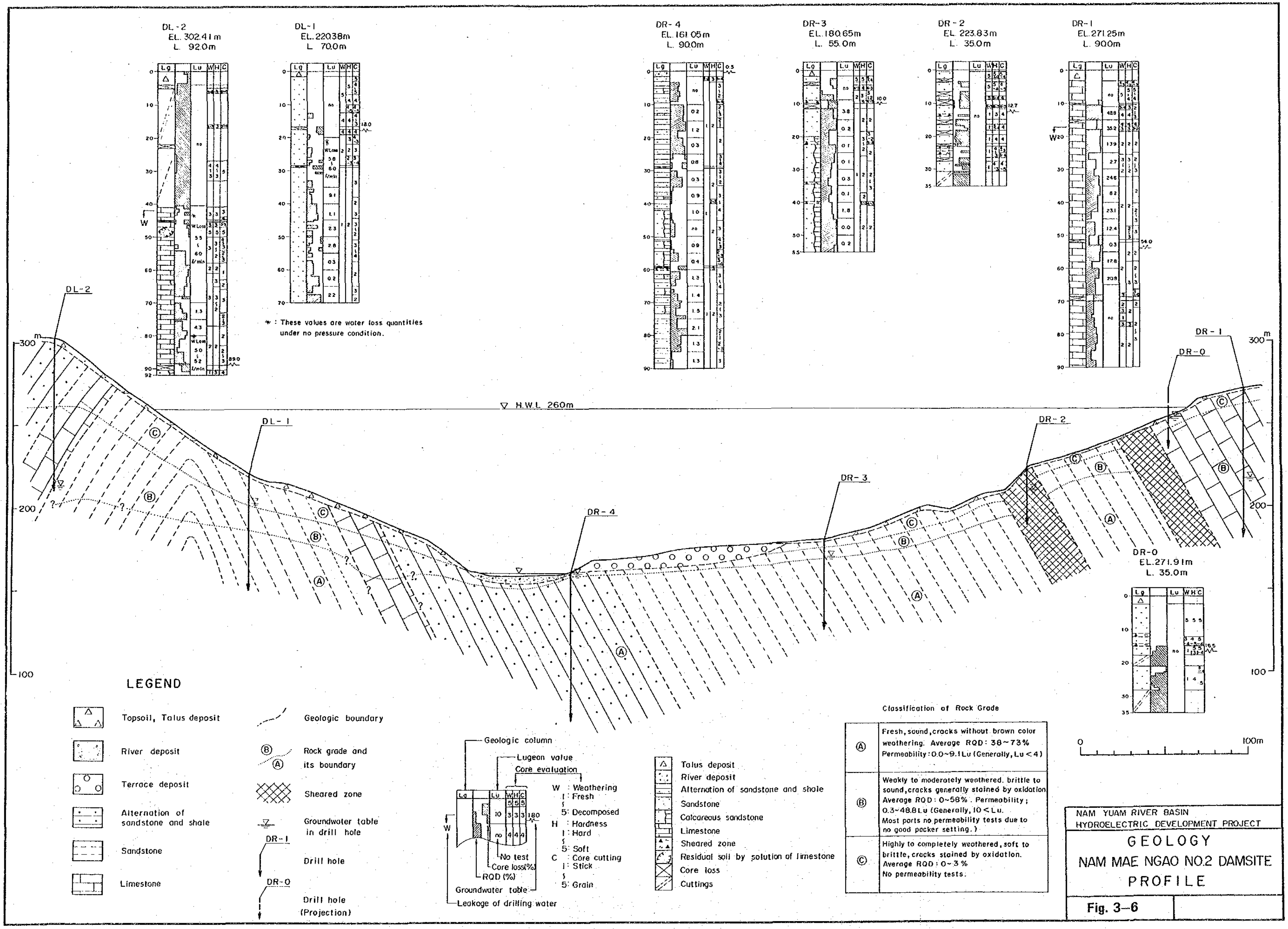
LEGEND

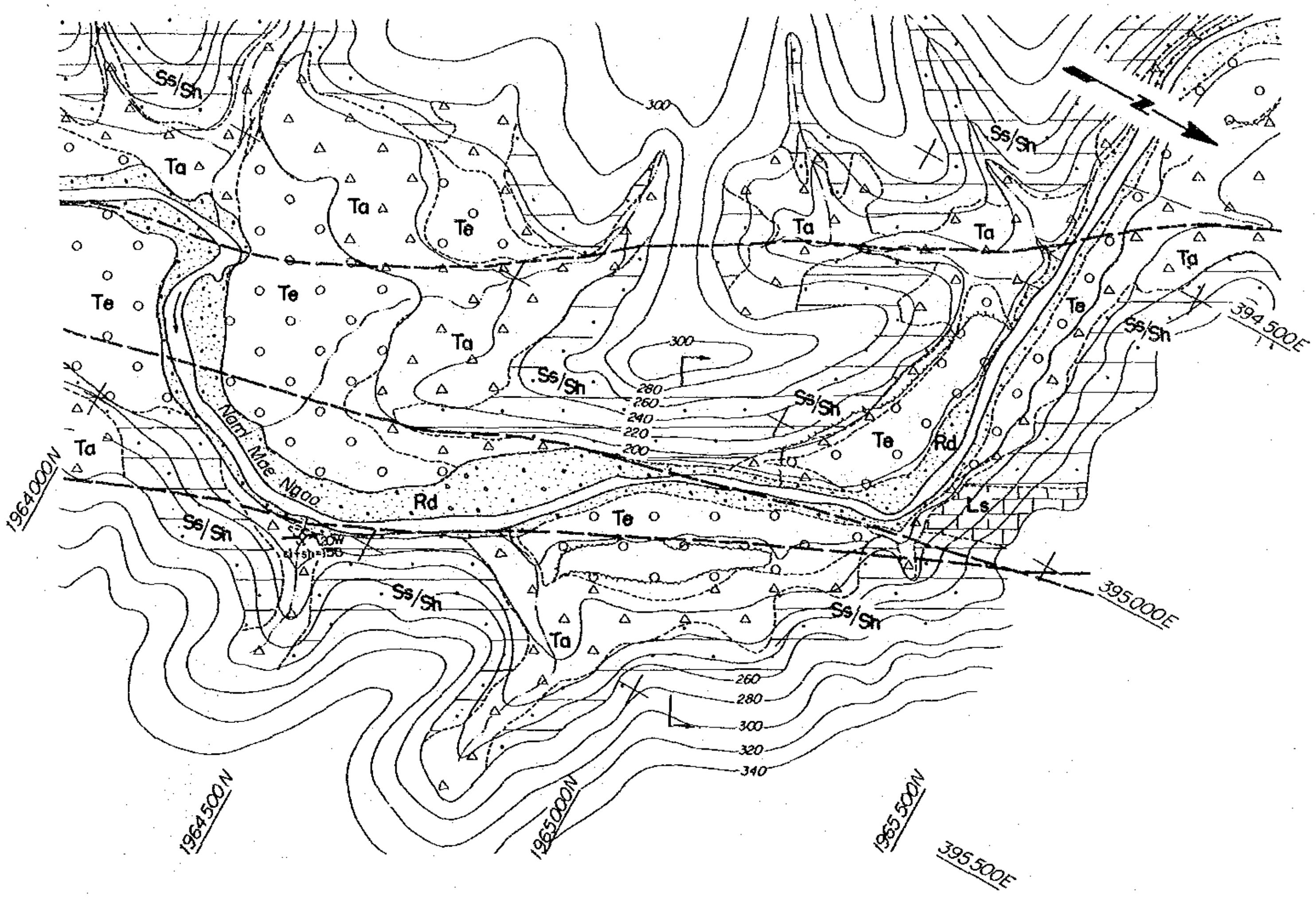
- Ta — Topsoil, Talus deposit
- Rd — River deposit
- Te — Terrace deposit
- Ss/Sh — Alternation of sandstone and shale
- Ls — Limestone
- Ch — Chert
- 70 50W — Strike and dip of strata
- Geologic boundary
- Fault (Confirmed)
- DR-1 — Drill hole
- Additional drill hole for feasibility study (Proposed)
- Ditto (Inclined drill hole)

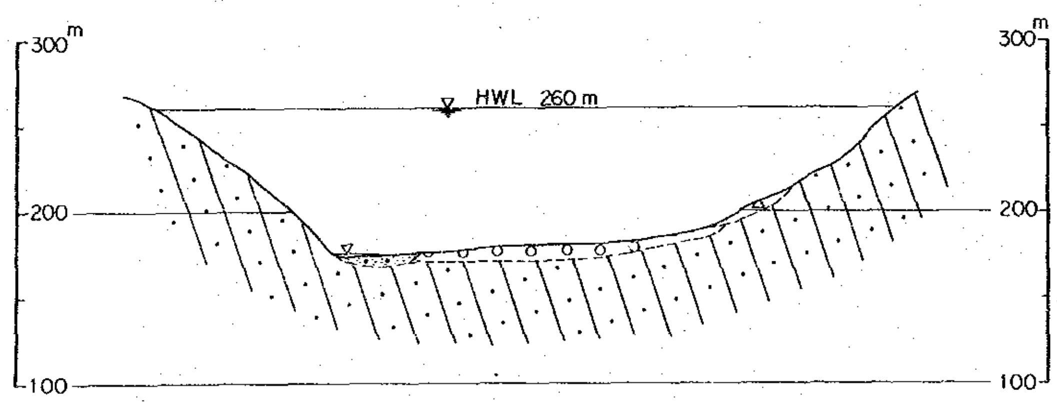
PLAN

0 — 500m

NAM YUAM RIVER BASIN HYDROELECTRIC DEVELOPEMENT PROJECT
GEOLOGY NAM MAE NGAO NO.2 DAMSITE PLAN
Fig. 3–5


DL-2 EL. 302.41m L. 92.0m
DL-1 EL. 220.38m L. 70.0m
DR-4 EL. 161.05m L. 90.0m
DR-3 EL. 180.65m L. 55.0m
DR-2 EL. 223.83m L. 35.0m
DR-1 EL. 271.25m L. 90.0m
DR-0 EL. 271.91m L. 35.0m
* : These values are water loss quantities under no pressure condition.
H.W.L. 260m
LEGEND
Topsoil, Talus deposit
River deposit
Terrace deposit
Alternation of sandstone and shale
Sandstone
Limestone
Geologic boundary
Rock grade and its boundary
Sheared zone
Groundwater table in drill hole
Drill hole
Drill hole (Projection)
Geologic column
Lugeon value
Core evaluation
W : Weathering
1 : Fresh
5 : Decomposed
H : Hardness
1 : Hard
5 : Soft
C : Core cutting
1 : Stick
5 : Grain
No test
Core loss(%)
RQD (%)
Groundwater table
Leakage of drilling water
Talus deposit
River deposit
Alternation of sandstone and shale
Sandstone
Calcareous sandstone
Limestone
Sheared zone
Residual soil by solution of limestone
Core loss
Cuttings
Classification of Rock Grade
Ⓐ Fresh, sound, cracks without brown color weathering. Average RQD: 38~73% Permeability: 0.0~9.1Lu (Generally, Lu < 4)
Ⓑ Weakly to moderately weathered, brittle to sound, cracks generally stained by oxidation. Average RQD: 0~58%. Permeability; 0.3~48.8Lu (Generally, 10 < Lu. Most parts no permeability tests due to no good packer setting.)
Ⓒ Highly to completely weathered, soft to brittle, cracks stained by oxidation. Average RQD: 0~3% No permeability tests.
0 100m
NAM YUAM RIVER BASIN HYDROELECTRIC DEVELOPMENT PROJECT
GEOLOGY
NAM MAE NGAO NO.2 DAMSITE
PROFILE
Fig. 3-6





LEGEND

- Ta — Topsoil , Talus deposit
- Rd — River deposit
- Te — Terrace deposit
- Ss/Sh — Alternation of sandstone and shale
- Ls — Limestone
- 60 70W — Strike and dip of strata
- 80 20W sh+cl=100 — Strike and dip of fault (sh+cl : width of shear zone and clay in cm)
- Geologic boundary
- Aerophoto lineament

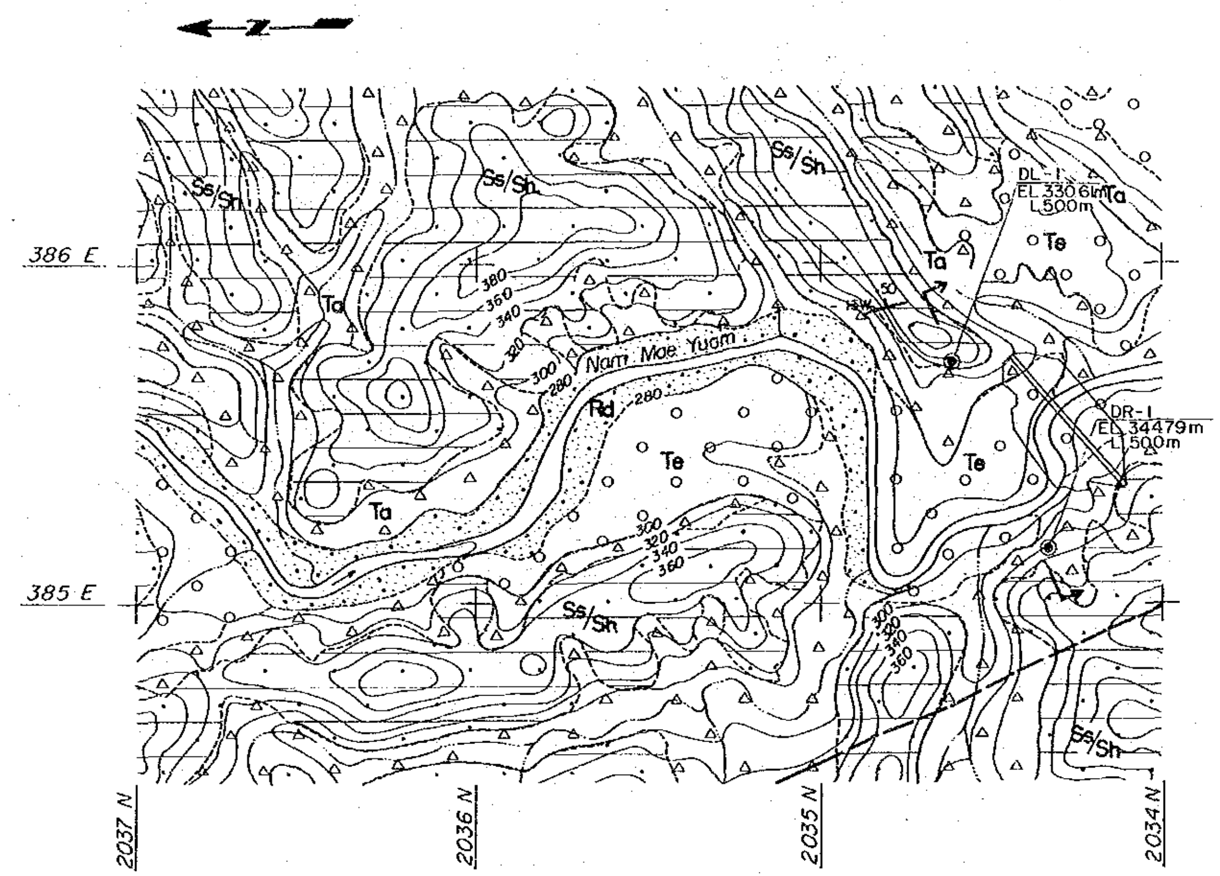
PLAN 0 — 500 m

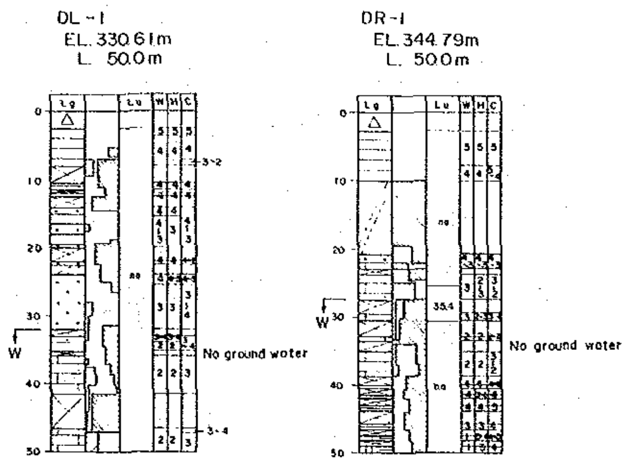
PROFILE 0 — 200 m

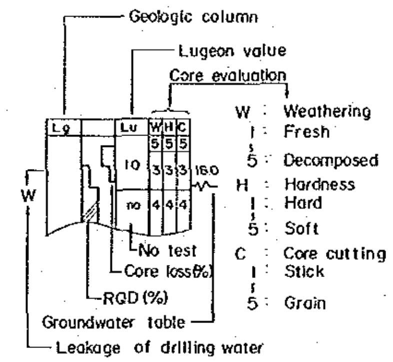
NAM YUAM RIVERBASIN HYDROELECTRIC DEVELOPEMENT PROJECT

GEOLOGY
NAM MAE NGAO NO.3 DAMSITE
PLAN AND PROFILE

Fig. 3–7



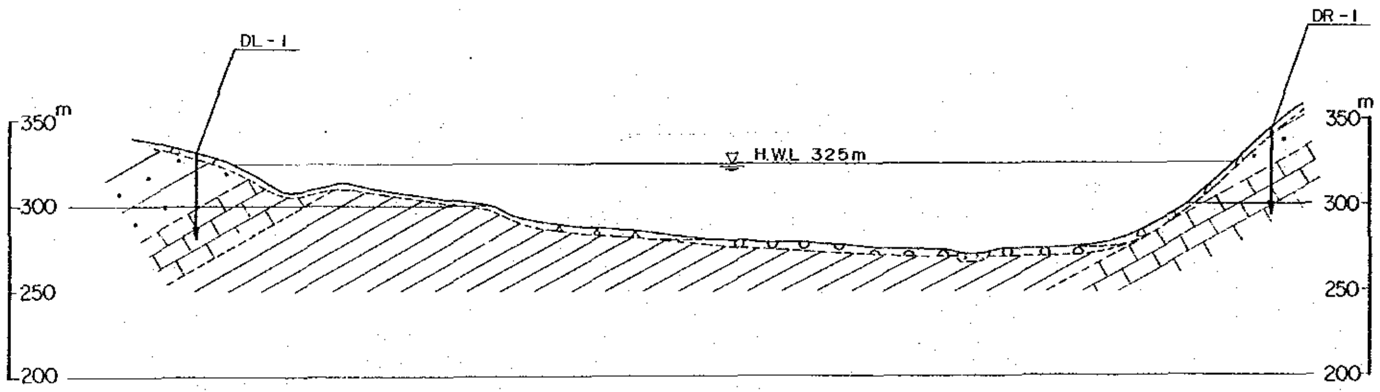




LEGEND

- Ta — Topsoil, Talus deposit
- Rd — River deposit
- Te — Terrace deposit
- Ss/Sh — Alternation of sandstone and shale
- Ls — Limestone
- 60 15W — Strike and dip of strata
- Geologic boundary
- Aerophoto lineament
- DL-1 — Drill hole

- Talus deposit
- Shale
- Alternation of sandstone and shale
- Sandstone
- Limestone
- Calcareous shale
- Core loss
- Cuttings



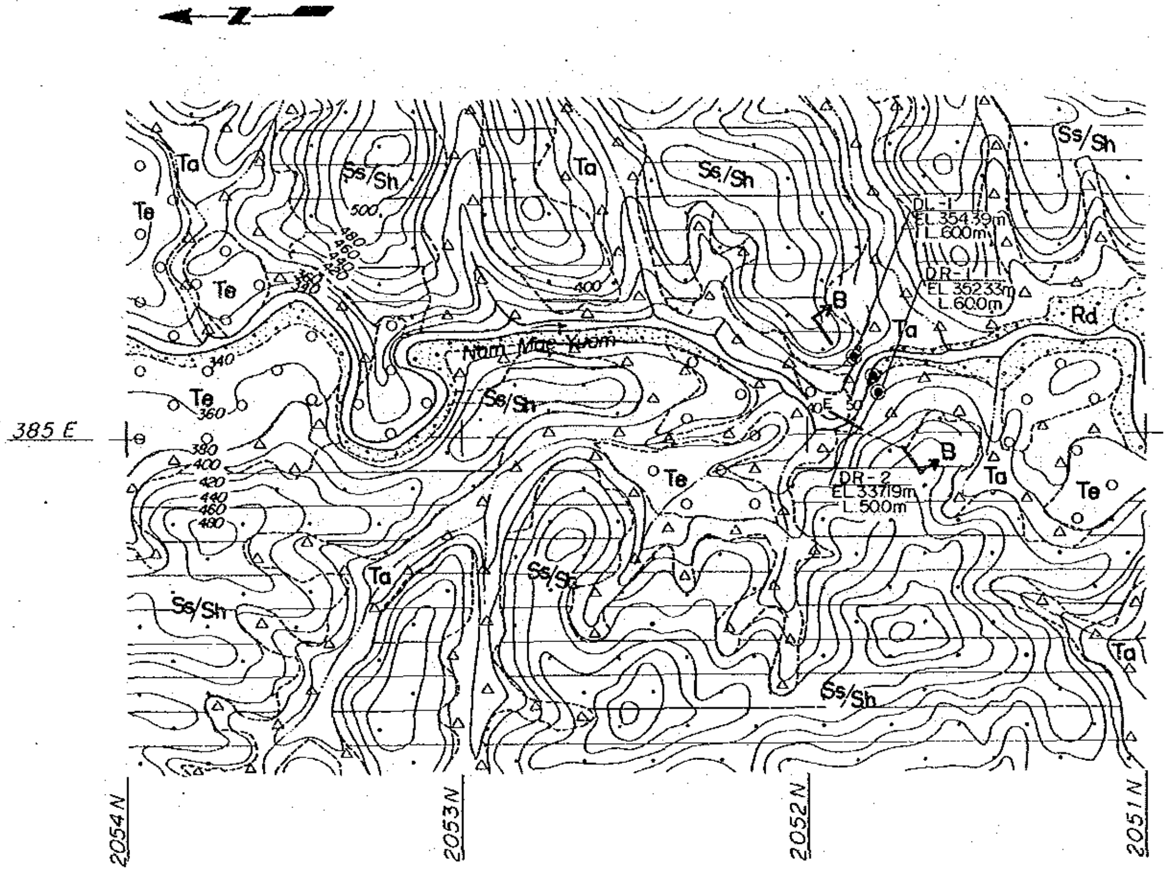
PLAN 0 — 1000 m

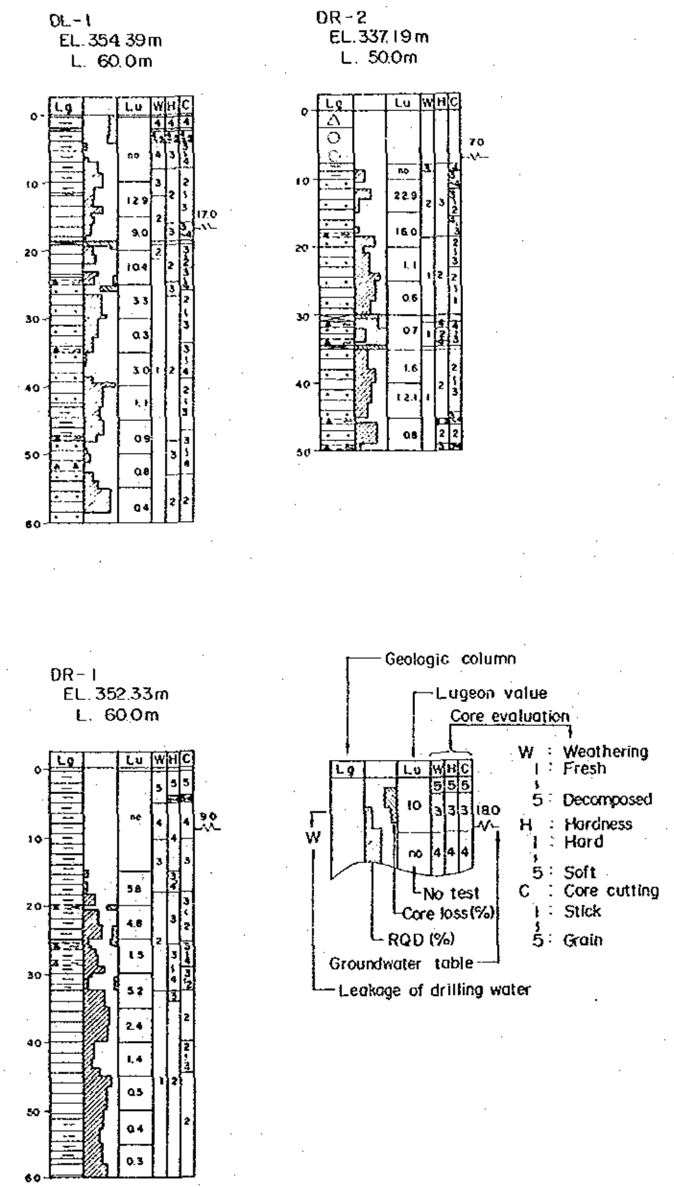
PROFILE 0 — 200 m

NAM YUAM RIVER BASIN
HYDROELECTRIC DEVELOPEMENT PROJECT

GEOLOGY
UPPER MAE YUAM 1 DAMSITE
PLAN AND PROFILE

Fig. 3–8

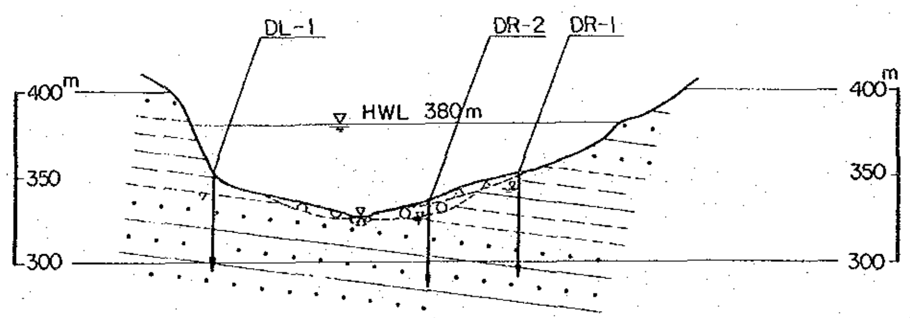




LEGEND

- Ta — Topsoil, Talus deposit
- Rd — River deposit
- Te — Terrace deposit
- Ss/Sh — Alternation of sandstone and shale
- Siltstone
- 60 40W — Strike and dip of strata
- Geologic boundary
- DL-1 — Drill hole
- Groundwater table in drill hole

- Talus deposit
- Terrace deposit
- Siltstone
- Shale
- Alternation of sandstone and shale
- Sheared zone
- Core loss



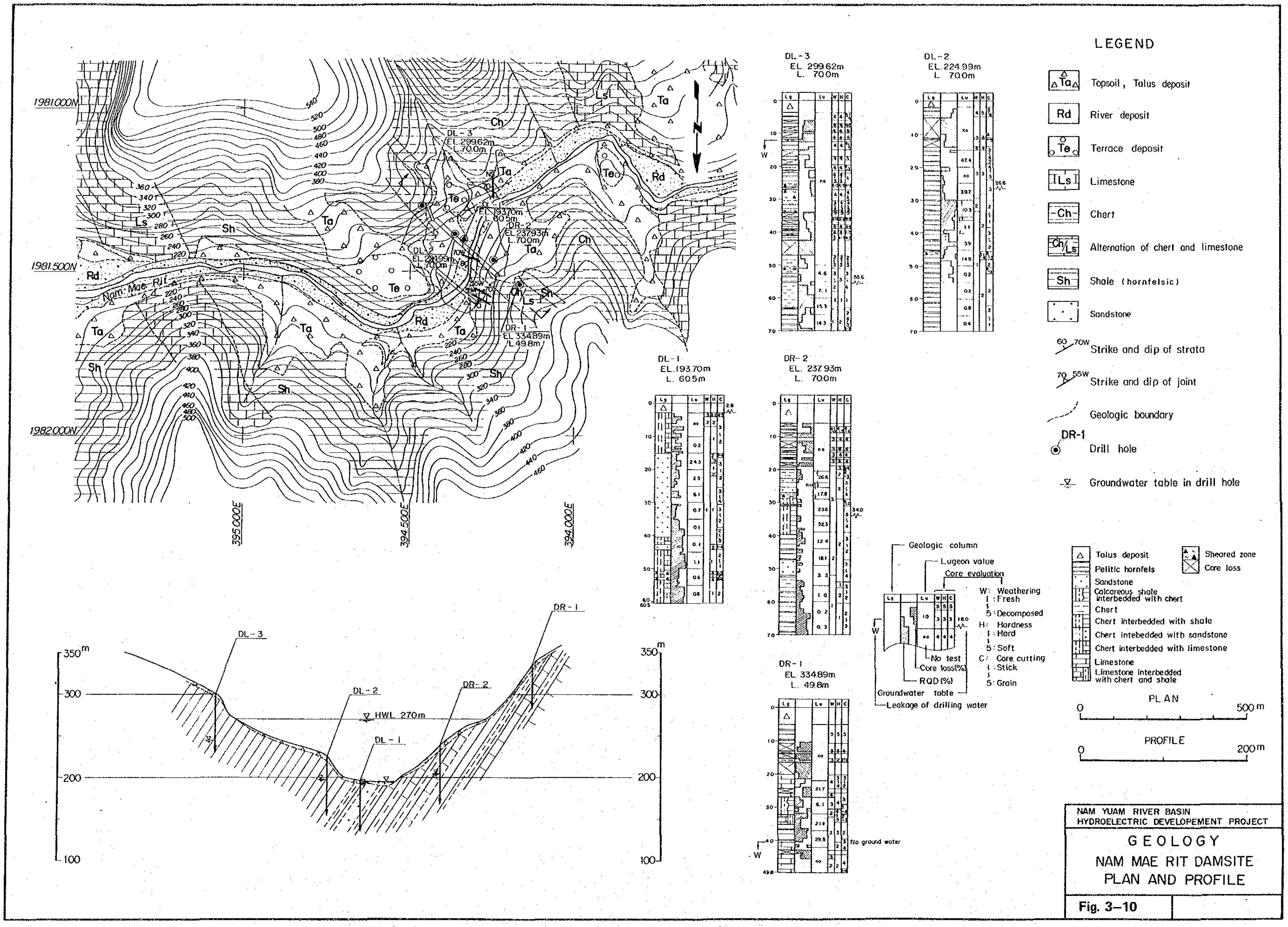
PLAN
0 — 1000m

PROFILE
0 — 200m

NAM YUAM RIVER BASIN
HYDROELECTRIC DEVELOPEMENT PROJECT

GEOLOGY
UPPER MAE YUAM 2 DAMSITE
PLAN AND PROFILE

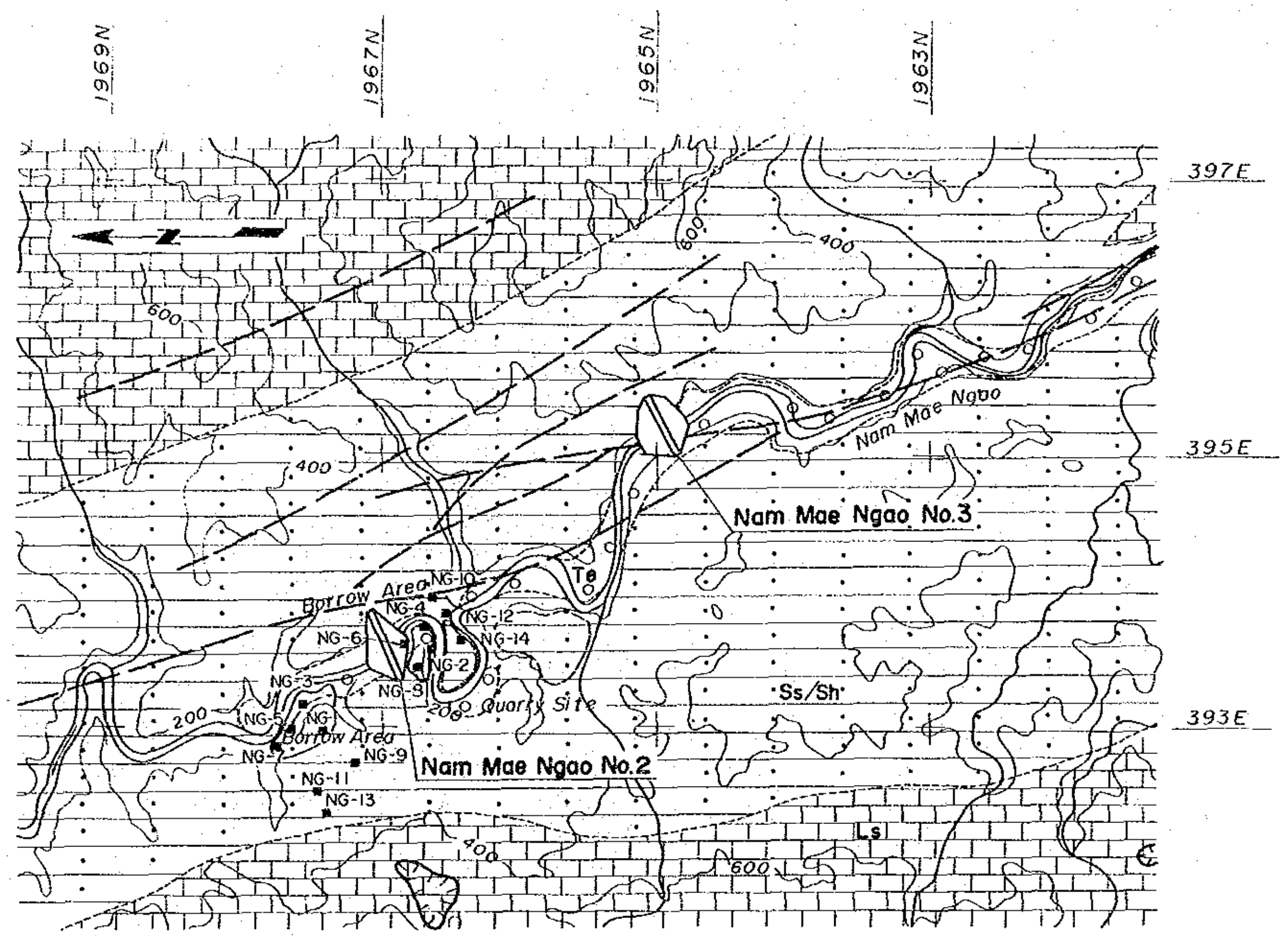
Fig. 3–9



NAM YUAM RIVER BASIN HYDROELECTRIC DEVELOPEMENT PROJECT

GEOLOGY
NAM MAE RIT DAMSITE
PLAN AND PROFILE

Fig. 3–10



LEGEND

- Te — Terrace deposit
- Ss/Sh — Alternation of sandstone and shale
- Ls — Limestone
- Sink hole
- Geologic boundary
- Aerophoto lineament
- Borrow area
- Quarry site
- Test pit

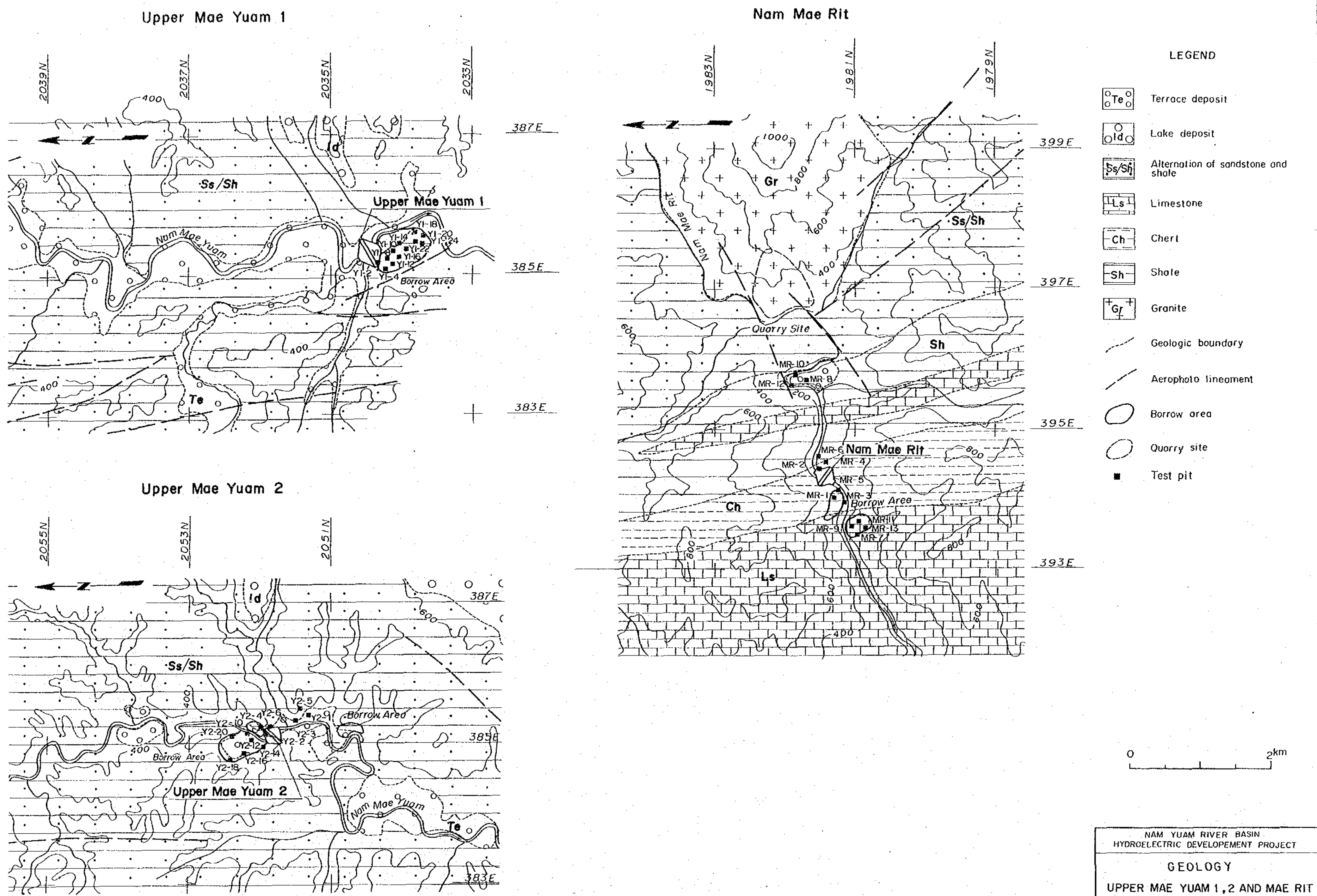
0 — 2km

NAM YUAM RIVER BASIN HYDROELECTRIC DEVELOPEMENT PROJECT

GEOLOGY

NAM MAE NGAO NO.2
BORROW AREA AND QUARRY SITE

Fig. 3–11



NAM YUAM RIVER BASIN HYDROELECTRIC DEVELOPEMENT PROJECT

GEOLOGY

UPPER MAE YUAM 1, 2 AND MAE RIT BORROW AREA AND QUARRY SITE

Fig. 3–12

CHAPTER 4. METEOROLOGY AND HYDROLOGY

CHAPTER 4 METEOROLOGY and HYDROLOGY

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CHAPTER 4. METEOROLOGY AND HYDROLOGY

4.1 Meteorological Outline in the Project Area

The project area belongs to a tropical monsoon region, and the annual climate undergoes the strong effect of monsoons. Namely, in the season of May to October, during which south-west monsoon from the Bay of Bengal is strong, there is a large amount of rainfall in the area, forming the rainy season, and on the contrary, in the season of November to April, during which northeastern monsoon coming from the continent blows strongly, makes the dry season. The annual average precipitation is approximately 1,300 mm.

Temperature is high through the year, about 27°C on an average. Particularly, in April which is just before the rainy season, the daily highest temperature reaches almost 40°C. December and January which are in the dry season is the lowest temperature period in the year, and the daily lowest temperature goes down to 10°C or so.

Humidity is also high through the year. It is about 85% in the plain at midstream of the basin and over 90% in the southern mountaineous region of the basin. March and April in the end of the dry season are the least humid months through the year, and it is 60% or so sometimes. In other months, humidity is almost constant.

Annual average evaporation in the basin is about 1,300 mm measured by Class A Pan. It is large in the midstream area and northern area of the basin and small in the southern area thereof. Evaporation is largest in March and April, the end of the dry season.

4.2 Gaging Stations and Weather Observatory Station in the Yuam River Basin

1) Gaging Stations

In the Yuam river basin, several runoff gaging stations and weather observatory stations have been operated by NEA, EGAT and MD (Meteorology Department) as shown in Table 4-1 and Fig. 4-1. The periods of observations are summarized in Fig. 4-2.

Of these gaging stations, Sop Han (NEA) and Ban Tha Rua (NEA) have been operated more than 16 years.

Three new gaging stations have recently been set up by EGAT for observation of runoffs of Ban Mae Ngao, Ban Mae Suat and Wang Khan. Since these three gaging stations situate closer to the respective project sites proposed in this study, they shall be selected as reference gaging stations to the individual projects.

Moreover, a few kilometers upstream of Mae Sariang, an irrigation facility was constructed and operated by RID since 1976 and daily quantities of irrigation water-take from the Yuam river and spillages over a weir, constructed across the river have been measured.

Sums of the daily quantities of these intakes and spillages then estimate daily river runoffs just upstream of the irrigation facility.

All of above records and informations can be utilized for estimations of the river runoffs at respective project sites contained in the Master Plan. The actual steps taken for these estimations are described in the section 4-4.

2) Weather Observatory Stations

Five weather observatories are in the area, as shown in Fig. 4-1. Meteorological parameters are measured at those observatories.

In addition to the above observatories, three new observatories have been built by EGAT at the same place of new gaging station; Ban Mae Ngao, Ban Mae Suat and Wang Khan. The measured data of these new observatories are also available for the study.

The periods of measurement are shown in Figs. 4-3 ～ 4-6 according to meteorological factors.

4.3 Meteorology

1) Precipitation

Precipitation has been measured at eight stations within the Yuam river basin, and the three out of the eight stations, Sop Han, Chom Chaeng and Mae Sariang, are close to each other so that these three stations can be regarded as one station practically. And, three observatory stations of Ban Mae Ngao, Ban Mae Suat and Wang Khan are new ones. Considering the size of the catchment area (approximately 6,000 km^2) and the localization of precipitation, observation of precipitation could not be sufficient.

The precipitation pattern for one year in the area is shown according to months in Table 4-2. Rainfall in the catchment area shows a conspicuous contrast between rainy and dry season, due to the effect of tropical periodic winds. Rainy season will start around May and continue until the latter half of October, while dry season will continue from November to the following April. The annual precipitation in the basin is approximately 1,300 mm on average, but about 90% of it is distributed in the six months of rainy season. During dry season the remaining 10% or so falls, but it normally falls only for several days intensively. Therefore, non-rainfall days continue practically for several weeks or months.

Precipitation in April and May which is the transient periods from dry to rainy season varies from year to year. Typically, rain starts falling from the latter half of April, and during early stage, rain falls once a week or 10 days with precipitation amount varying largely; occasionally falls a large amount. Following this, the interval of rainfall will shorten gradually, and as it enters the latter half of June, rain falls almost every day. The amount will reduce slightly in June and July, and increase again in the latter half of August, and it will gradually reduce again from October and go down to almost none in November. As noted in

Section 4.1, "Meteorological Outline", monsoon blows from the Bay of Bengal in rainy season, conveying rain-laden clouds, from south. As the result, rainfall in rainy season is created by travelling rain clouds and concentrated into some hours during a day at a place, while rainfalls in dry season seem to be localized by strong solar radiation.

Rainfall is in general originated by the phenomenon that rain-laden clouds are blocked with mountains and elevated high. In this project area too, precipitation is heavy, about 1,600 mm annually, at Ban Tha Rua which is located in mountaineous area in the southern part and also close to the sea, while precipitation at Sop Han and Mae Sariang located in plain area at midstream is less, about 1,200 mm per annum. Mae La Luang located in the mountain area but in the northern part gives relatively less annual precipitation, about 1,300 mm.

2) Temperature

Temperature has been measured at five stations; Sop Han, Ban Tha Rua, and three new observatory stations. The annual averages of daily highest and lowest temperature are about 33°C and 22°C respectively.

The daily lowest temperature goes down to the lowest, 13°C or so, in February. It went down to 10°C or less in some days, and 6°C was recorded at Ban Tha Rua in January, 1974. As it comes closer to rainy season the temperature goes up, and during rainy season it is nearly constant at 23°C or so.

Meanwhile, the daily highest temperatuer becomes highest, 38°C or so, in April, right before beginning of rainy season. The temperature had exceeded 40°C in some days, and the highest was recorded for 44.5°C at Sop Han in April, 1981. It will start decreasing as rainy season begins, and go down to 30°C or so in August. After that, it again rises slightly until towards October. As entering dry season, it again decreases down to 30°C or so.

The difference between daily highest and lowest temperature becomes largest in March which is in the latter half of dry season, reaching 21°C or so. As it enters rainy season, the difference is getting smaller, reaching 7°C or 8°C in July or August.

3) Relative Humidty

In the project area, the relative humidity has been measured at Sop Han, Ban Tha Rua, and three new observatory stations. The annual average humidity was 86% at Sop Han and 94% at Ban Tha Rua, indicating that it is higher by about 10% at Ban Tha Rua which is in mountaneous area than at Sop Han. The reason for this is that precipitation is heavier at Ban Tha Rua while evaporation at there is less as described in the next section. The variation during one year is similar at both the two spots; Sop Han and Ban Tha Rua, and the relative humidity becomes lowest in April and May, right before the rainy season, while it is almost constant throughout the rest of one year.

4) Evaporation

Evaporation in the project area has been measured at six stations; Mae La Luang, Sop Han, Ban Tha Rua and three new observatory stations. The average of monthly evaporation is shown in Table 4-3. The annual total evaporation is approximately 1,400 mm at Sop Han and Mae La Luang, and 1,200 mm at Ban Tha Rua. Ban Tha Rua is located in southern mountaneous area, having heavy precipitation and less evaporation. The variation during one year shows the trend similar to temperature, and the annually-highest evaporation has been experienced in April, just before the rainy season. Following this, evaporation reduces continuously until August, and it again increases in September and October, then again decreases in the following dry season. In April, which evaporation becomes largest during a year, the daily evaporation becomes as much as 6.0 mm.

4.4 Runoff Discharge

1) Estimation of daily runoff in 1979 of Sop Han.

The records of the runoff in 1979 of this gaging station are completely missing. [1)]

1) The reason of missing is in non-acceptance of actually observed data.

Estimation of these missing data was made using a regression model:

$$Yi = b_0 + b_1\ Xi \quad (1)$$

Where,

Yi = daily river runoff of Sop Han in cms,

Xi = daily river runoff just upstream of the RID irrigation weir, Mae Sariang in cms, and

bo, bl = parameters.

Observed common period to Yi and Xi is 8 years, i.e. from 1976 to 1978 and from 1980 to 1984. The values of parameters were calculated by applying an usual least square technique based on daily data so that the model

$$Yi = -2.096 + 1.05096\ Xi \quad (2)$$

is fixed.

Fig. 4-7 shows this regression line together with a scattergram of observed values of Yi's vs. Xi's for the regression period. The model is then applied for estimation of the missing values by substituting the observed daily runoffs in 1979 to Xi just upstream of RID irrigation weir.

The results are summed up to monthly values which are shown in Table 4-4. By inserting these results into observed series, continuous runoff data of Sop Han for 18 years (1967 - 1984) have been completed. The monthly values of these results are shown in column 1967 through 1984 of Table 4-5.

2) Restoration of Irrigation-use Water Quantities to Runoff Records of Ban Tha Rua.

As before mentioned, some amount of the Yuam river runoffs have been extracted for irrigation use since 1976. The observed river discharge records from 1976 at Ban Tha Rua gaging station which situates downstream of the RID weir are therefore smaller than the river discharge data which have been observed before 1976. Thus the observed data at the present don't show natural river runoffs, being the results of the artificial water extraction.

The river runoff observation of Ban Tha Rua was started in 1969, hence the observed runoff records of Ban Tha Rua from 1969 to 1975 have a different charactor from those actually observed from 1976 to present, in other words, the character of the runoff records from 1976 to present are not homogenous with the past records.

The homogeneity of data is indispensable whenever any regression analysis is to be applied for.

Thus the observed runoff records of Ban Tha Rua and those of irrigation water-use are added together day by day to restore the natural runoff records of Ban Tha Rua.

The monthly values of these restored runoffs are shown on column 1976 through 1984 of Table 4-6.

3) Runoff Estimate Using Multiple Regression Model

In order to extend the runoff data of Ban Mae Rit and Ban Mae Ngao to the period for which the observation records of Sop Han and Ban Tha Rua are available, a multiple regression analysis was applied.

First, various scattergrams were plotted as shown in Fig. 4-8 through Fig. 4-12. For example in Fig. 4-8, the scattergram of daily runoffs of Ban Mae Suat (Yi) vs. daily runoffs of Sop Han (Xi) are plotted.

It can be seen from these scattergrams that the following linear model will be sufficient for the present analysis.

Model : $Y = b_0 + b_1 X_1 + b_2 X_2$ (3)

where,

Y = daily runoff of Ban Mae Suat or Ban Mae Ngao,
X_1 = daily runoff of Sop Han, and
X_2 = daily runoff of Ban Tha Rua.

By applying the usual least square method, the following normal equations are obtained :

$$A_{1,1} b_0 + A_{1,2} b_1 + A_{1,3} b_2 = B_1$$
$$A_{2,1} b_0 + A_{2,2} b_1 + A_{2,3} b_2 = B_2 \quad (4)$$
$$A_{3,1} b_0 + A_{3,2} b_1 + A_{3,3} b_2 = B_3$$

Where,

$$A_{1,1} = n$$
$$A_{1,2} = A_{2,1} = \sum X_{1i}$$
$$A_{1,3} = A_{3,1} = \sum X_{2i}$$
$$A_{2,2} = \sum X_{1i}^2$$
$$A_{2,3} = A_{3,2} = \sum X_{1i} X_{2i} \quad (5)$$
$$A_{3.3} = \sum X_{2i}^2$$
$$B_1 = \sum Y_i$$
$$B_2 = \sum X_{1i} Y_i$$
$$B_3 = \sum X_{2i} Y_i$$

Solving the simultaneous linear equatiuons (4), the values of parameter b_0, b_1 and b_2 were obtained.

In case of runoff estimation of Wang Khan the model:

$Y = b_0 + b_1 X_1$ (6)

where,

Y = daily runoff of Wang Khan, and
X_1 = daily runoff of Sop Han

is considered to be appropriate because the Wang Khan gaging station is located only about 30 km upstream of the Sop Han gaging station and no large tributaries are joined to the main river in-between them. The calculation of equation (6) can be done in the same way as above except that all values of $A_{1,3}$, $A_{3,1}$, $A_{2,3}$, $A_{3,2}$, $A_{3,3}$ and B_3 are vanished in the equations (4).

The results of calculations are shown Table 4-7 through Table 4-9 and the obtained models are summarized as follows:

1) for the daily runoff (Y) of Ban Mae Suat:

$$Y = 2.345 + 0.05734\ X_1 + 0.1112\ X_2 \qquad (7)$$

2) for the daily runoff (Y) of Ban Mae Ngao:

$$Y = 2.089 - 0.5418\ X_1 + 0.6869\ X_2 \qquad (8)$$

3) for the daily runoff (Y) of Wang Khan:

$$Y = 2.875 + 0.6518\ X_1 \qquad (9)$$

where,

X_1 = daily runoff of Sop Han, and
X_2 = daily runoff of Ban Tha Rua.

All the corelation coefficients obtained exceeded 0.90. This implies that response variable Y and predictor variables X_1 and X_2 are linearly associated with a high degree and the assumptions on the linear model were justified.

To see the appropriateness of the model from a different view point, the values Yi were calculated using the obtained models for the periods where the observed data are available. The results are shown in Fig. 4-13 through Fig. 4-15.

From these plottings it is seen that the estimated runoffs conform fairly well to the observed runoffs. Incidentally, the dotted lines in the figures show erroneously estimated runoffs (not adopted in this study) for reference.

These runoffs are calculated basing on an assumption that the runoffs of two stations are linearly proportional to their respective catchment areas.

A glance at the plotted results will show clearly how the latter method is misleading.

Thus the runoffs of Ban Mae Suat and Ban Mae Ngao from 1969 to 1983 and those of Wang Khan from 1967 to 1983 were all estimated using the regression models and are shown on the corresponding columns in Table 4-10 through Table 4-12 and plotted on Fig. 4-16 through Fig. 4-18.

4) Runoff Estimate Using Time Variant Unit Hydrograph Method

Up to this point the estimated runoff periods for the three new gaging stations have come up for about 14 - 17 years. (see Fig. 4-2)

Adding these estimated runoffs to the actually observed runoffs which are only one to two years available, we had altogether about 15 - 18 years of runoff data in hand.

For the planning of water resouces development project, river runoff informations, spanning over at least the whole project life period are preferable. Since the length of life span adopted for an economic analysis of hydro power project is usually 50 years, the above lengths of runoff estimations are shorter than required.

Now at Mae Sariang, daily rainfalls have been observed since 1959 without interuption. Since this length of period is longer than those of runoffs, runoffs from 1960 to 1968 could be estimated by certain appropriate method correlating these rainfalls to runoffs for the common period for which both rainfall and runoff data are existed.

Several methods are available for the purpose of this correlation. One of them is the "Tank Model" method which was adapted in the feasibility report of the "Nam Mae Yuam Hydroelectric Development Project" studied by JICA in 1984. This method is well known and has been successfully applied to many rivers in Japan and in many other countries too.

Roughly speaking, this method aims to correlate each cluster of rainfalls to each recession of runoffs. However, if there are only a very few rainfall observation stations existed in and around a relatively vast catchment area, the reliability of the results obtained by this method may be lower. In other words, dependability on the availability of the areal rainfall data is crucial with this method.

Since we have only one rainfall station observed more than 30 years in the Yuam river basin, that is, we have only one point rainfall records at Mae Sariang within a catchment area of 5,770 km^2 (Ban Tha Rua) available, cares must be taken to apply this method to this river basin.

A new method [1] which was published in the Proceedings of Japan Society of Civil Engineers, No. 336, August 1983, pp. 47-53 (in Japanese) and in the Transactions of JSCE, Vol. 15, 1983 (an excerpt version in English) has been applied in the present study. The new method utilizes the Linear Programming (LP) program to determine the coefficients of the so-called "Time Variant Unit Hydrographs" by minimizing the sum of absolute differences of the observed and estimated runoffs.

The Yuam river is already taken up as an example application of the method and the results were discussed.

According to this paper, the method is especially suitable to the rivers in the tropical region where the climatical change between dry and rainy season is conspicuous.

Thus two individually estimated runoffs of the Yuam river are now available to us. It seems to be interesting and advantageous for us to compare these results. We therefore will make the comparison and adopt the method which will best conform to the Yuam river.

The comparison is shown in Fig. 4-19 and the estimated runoffs by each method are listed in Table 4-13 and Table 4-14 respectively. From these results it is seen that the runoffs estimated by the Time Variant Unit Hydrograph method are generally more conformed to the observed runoffs than those estimated by the Tank Model.

1) The method was also applied for several rivers in Thailand by M. Nakamura in his thesis No. WA-82-14, "Runoff Analysis by Linear Hydrologic System", 1982, Asian Institute of Technology.

Although there are many other methods such as basin storage function method, Sacramento model, etc., we will exclude those methods because all of them including the above-mentioned two methods belong in principle to the so-called "black box model" family and without the fairly reliable areal rainfall observations, the estimated runoffs using any black box model will have more-or-less the same order of fluctuations or errors.

Thus the runoffs of Sop Han and Ban Tha Rua from 1960 to 1968 are estimated by the new method.

The actual computation for this study was performed at AIT Regional Computer Centor inputting the updated rainfall and runoff data from those used in the above mentioned paper.

The principle and the method of application are described in the referenced paper, so the explanation of the method will not be repeated here.

Table 4-15 and Table 4-16 show the coordinate values of the Time Variant Unit Hydrographs thus obtained by the computation.

Using these results, the runoffs of Sop Han and Ban Tha Rua are extended as are shown in Table 4-5 and Table 4-6 respectively.

Again by applying the regression models (7), (8) and (9), the runoffs at the three new gaging stations were further estimated for longer period by substituting the above extended runoffs into X_1 and X_2 in the equations. Note however that since this time we are dealing with monthly data, the constant terms, b_0 in equation (7), (8) and (9) should be multiplied by the number of days in a month. (coefficients of X_1 and X_2 remain unchanged.)

The results are shown in Table 4-14 through Table 4-16 and plotted on Fig. 4-16 through Fig. 4-18. As can be seen from these results, we now have river runoff data for 25 years for each of the three new gaging stations.

The river runoffs at each project site were then estimated by simply multiplying the catchment area ratio (of the project site to the gaging station) to the above estimated runoffs of the corresponding gaging station.

The finally estimated runoffs at each project site were used as basic runoff data for planning the project and the numeric values themselves will be seen in the tables of reservoir simulation case studies.

It seems appropriate to attach a comment here.

Throughout this hydrological analysis, the most crucial point is that the periods of runoff observations of the three new gaging stations are relatively short. Since the reliability of the regression analysis depends entirely on the length of periods during which the object gaging station to be regressed have the same common period of observations as the base gaging stations, any conclusions that will be obtained basing upon the short regression period, should be interpreted as aproximate.

It is recommended therefore the present hydrological study should be refined when the period of observations of the three new gaging stations will be accumulated by at least two years.

5) Extraction of evaporation losses

Evaporation losses from reservoir surfaces shall be extracted from the reservoir storages before the reservoir simulation study is attempted. The loss is calculated by the empirical equation as follows.

$$Q = 0.7AH \qquad (10)$$

where,

Q : evaporation loss from a reservoir, m^3

A : reservoir water surface area, m^2

H : evaporation observed by a class A pan, m

Evaporations have been observed at some of the gaging stations in the basin by class A pan.

Since the reservoir surface area varies month by month due to reservoir operation, a pre-simulation study is needed to calculate the monthly evaporation losses by the formula (10). Therefore, the pre-simulation study using the raw inflow data have been done.

Then, the evaporation losses were calculated by the formula (10) and extracted from the inflow values and net inflow values were obtained as shown in Table 4-17 and Table 4-18.

These net inflows will be used as the inflow data for the reservoir simulation study as will be explained in the Chapter 5. Notice that since the quantities of evaporation losses are relatively small comparing with the inflow quantities, effects of the extraction of evaporation losses will be almost negligible for the reservoir simulation study.

4.5 Sedimentation

Sediments have been measured at three stations in the area; Ban Tha Rua, Sop Han and Chom Chaeng. Out of them, two stations of Ban Tha Rua and Sop Han measure the main stream. To observe the condition of sediments in the similar basin, the data at Tha Song Yang along the Moei river were also referred to, although it is out of the basin of concern.

Measurement has been done for suspended sediment in terms of weight and in these tables the volume calculated by the unit weight obtained with the equation below is also given.

The unit weight of suspended sediment after settling down in the reservoir was obtained with the following equation:

$$W_{av} = W_1 + 0.434 K [\frac{t}{t-1} (\ln t-1)]$$

where W_{av} : average unit weight of sediment after t years (gr/cm^3)

W_1 : unit weight of initial sediment (gr/cm^3)

K : coefficient

t : number of years

This yields W_{av} : 1.30gr/cm^3

As mentioned above, measurement has been conducted for suspended material, and thus, for actual sediment, bed load must additionally be taken into account. Referring to various reports, bed load have been assumed for 20% in terms of the volume ratio.

The estimated sediment obtained is as follows:

Ban Tha Rua (5,770 km^2) : 276.0 m^3/km^2/yr
Sop Han (2,496 km^2) : 139.8 m^3/km^2/yr
Tha Song Yang (8,360 km^2) : 208.4 m^3/km^2/yr

280 m^3/km^2/yr which was slightly modified one to be larger than that of Ban Tha Rua was adopted as design sediment. The total sediment volumes for 100 years are calculated at the three sites of Nam Mae Ngao (No.2 Site) Nam Mae Rit and Upper Mae Yuam 1. These amount of