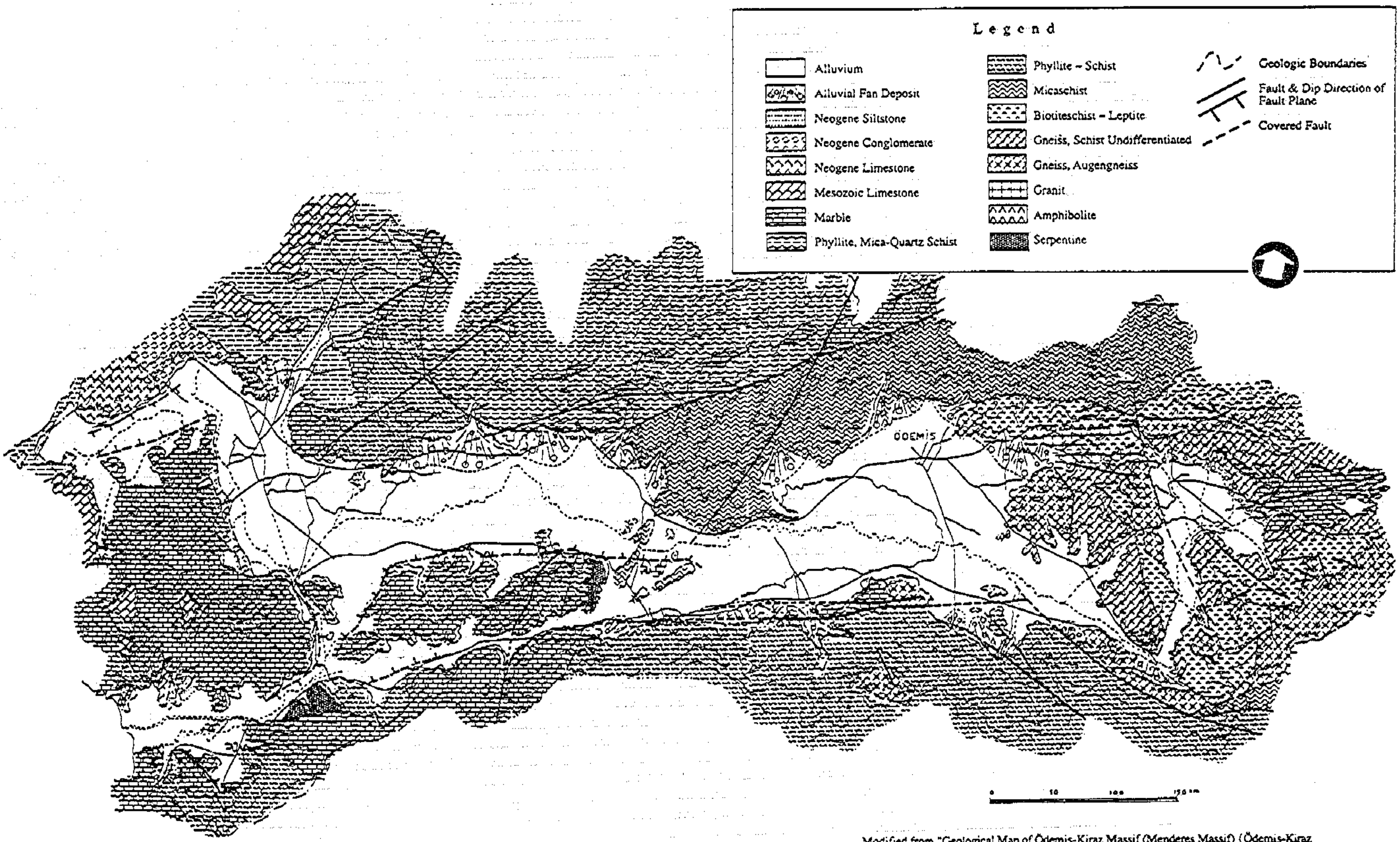
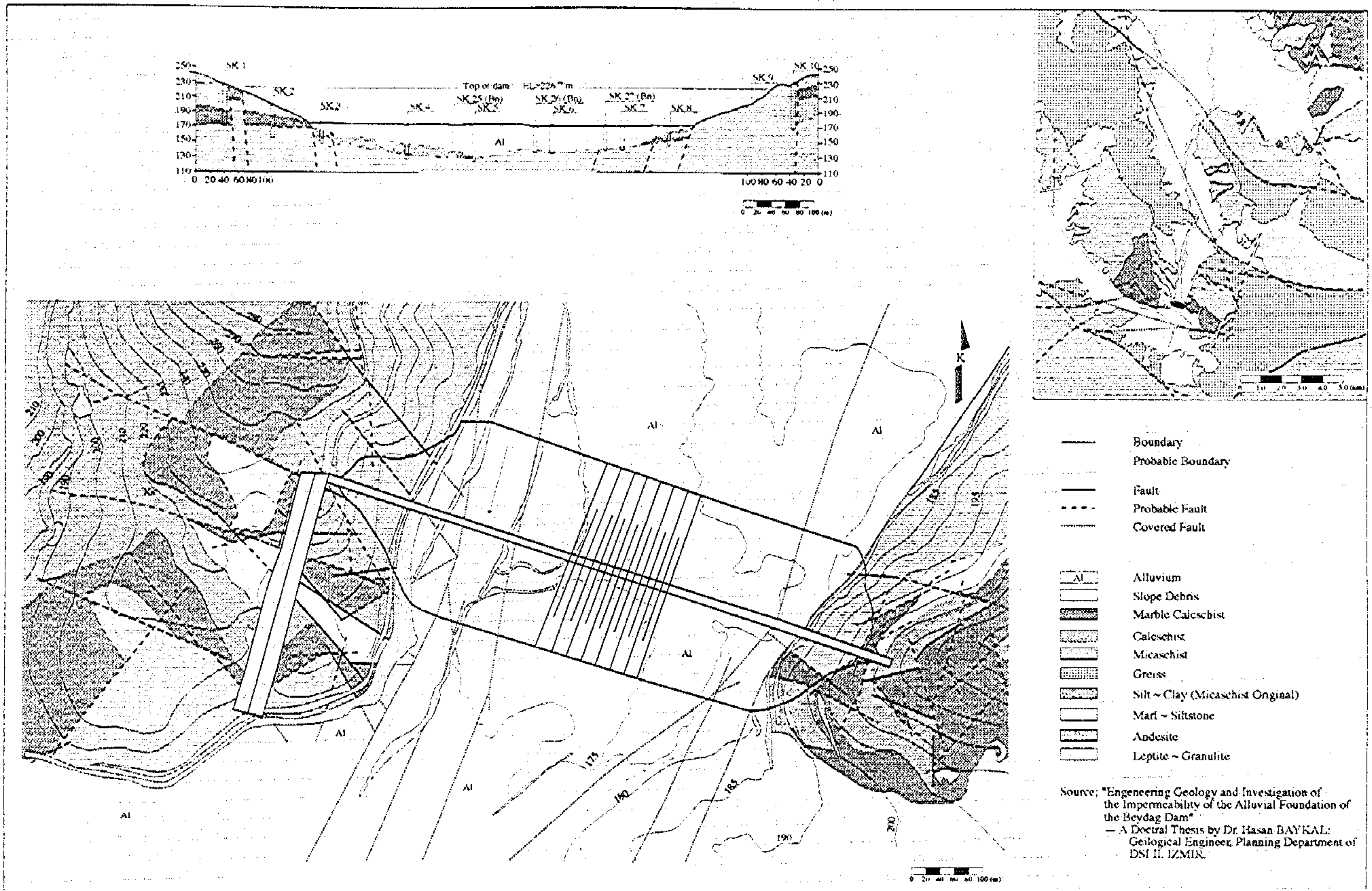
FIGURES



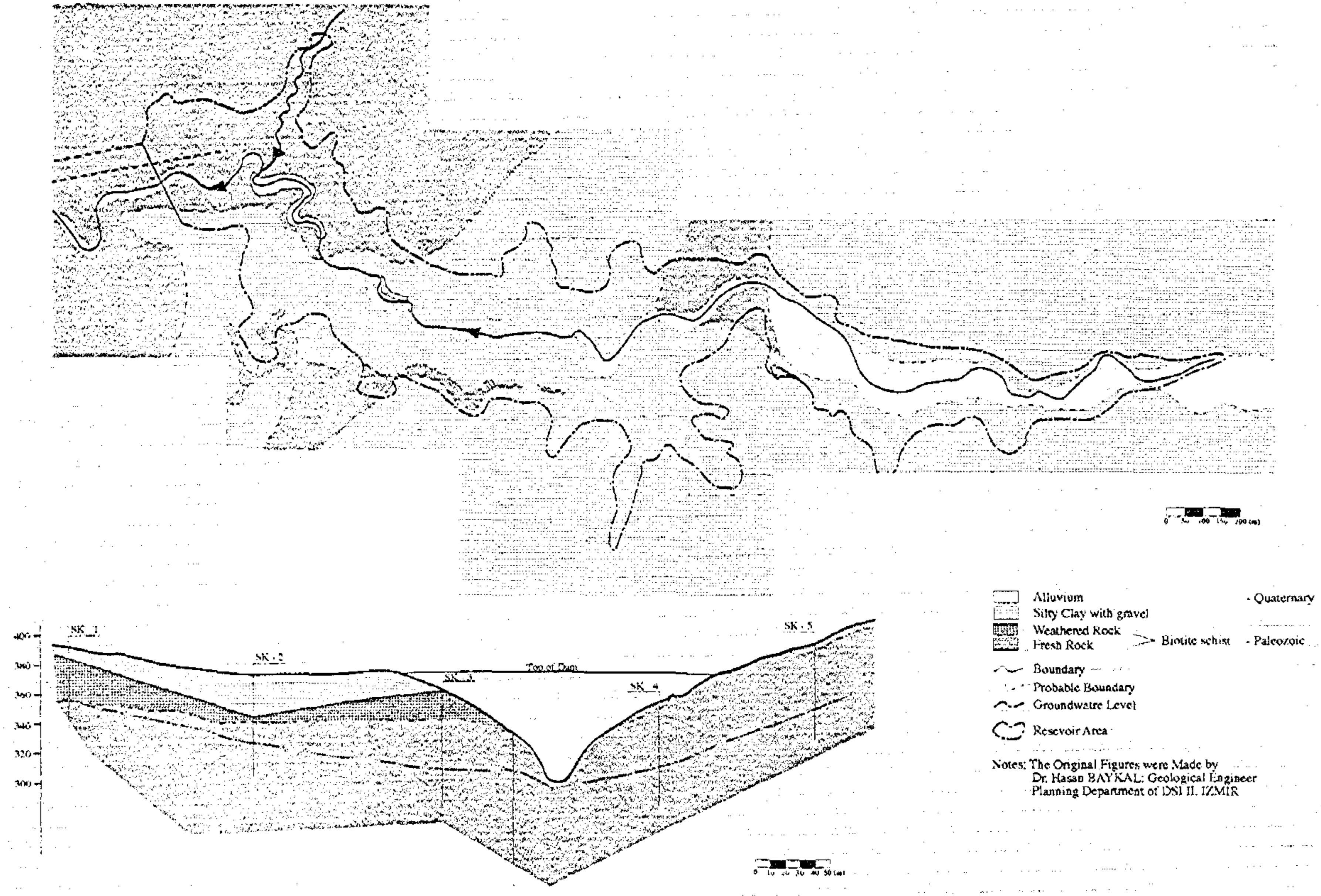
Modified from "Geological Map of Ödemiş-Kiraz Massif (Menderes Massif) {Ödemiş-Kiraz Asmasifi'nin (Menderes Masifi) Jeoloji Haritası}", MTA, IZMIR, and "Hydrogeologic Map of the Küçük Menderes Plain {Küçük Menderes Ovası Hidrojeoloji Haritası}".DSI.

Figure-B.1
Geological Map of Küçük Menderes River Basin



Source; "Engineering Geology and Investigation of the Impermeability of the Alluvial Foundation of the Beydag Dam"
— A Doctral Thesis by Dr. Hasan BAYKAL:
Geological Engineer, Planning Department of DSI II. IZMIR.

Figure-B.2 Geological Map of Beydağ Dam Site and Geological Profile of Dam Axis



Notes: The Original Figures were Made by
Dr. Hasan BAYKAL: Geological Engineer
Planning Department of DSI II. IZMIR

Figure-B.3 Geological Map around Aktas Dam Site and geological Profile Dam Axis

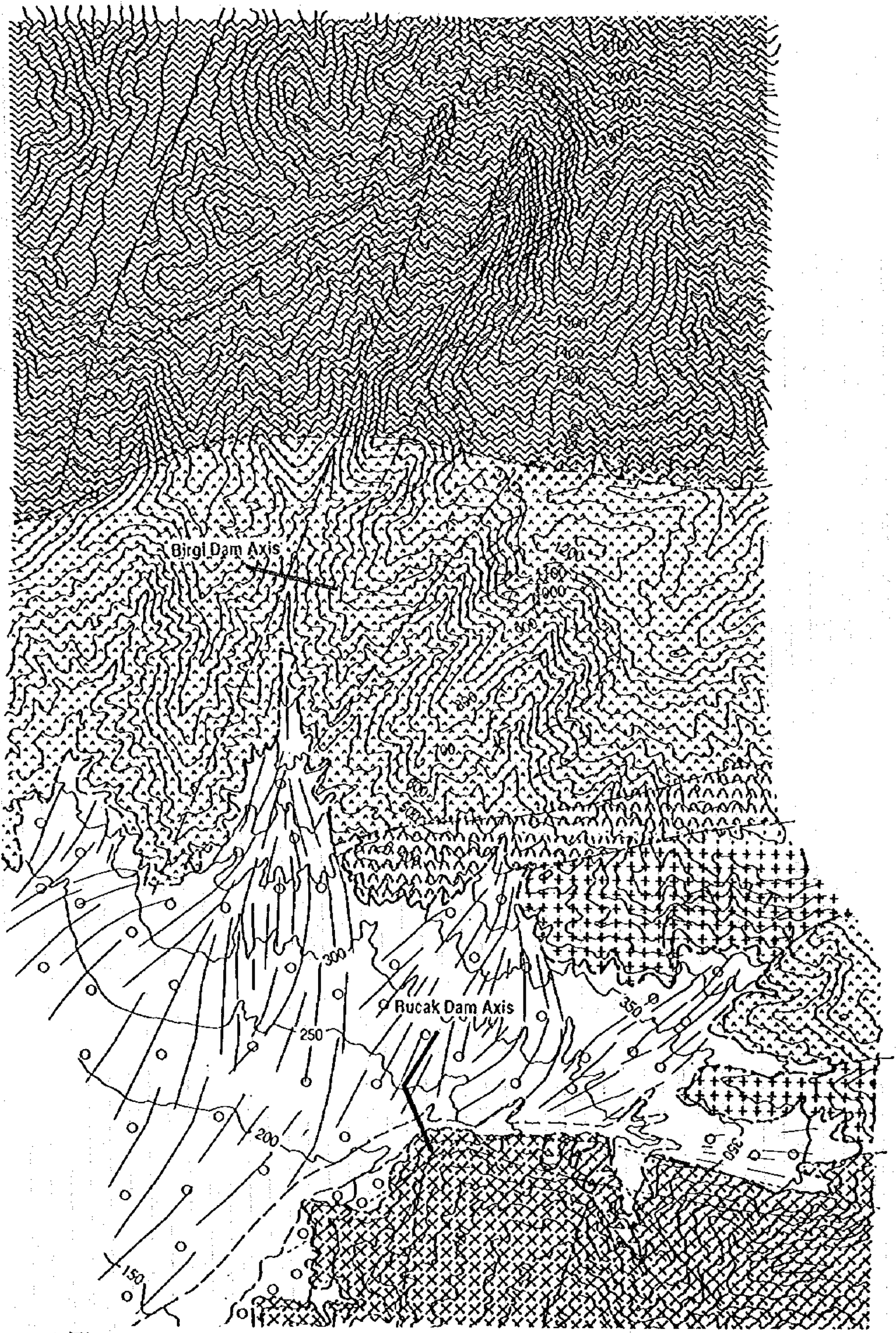


Figure-B.4(1) Geological Map around Birgi & Bucak Dam Axes
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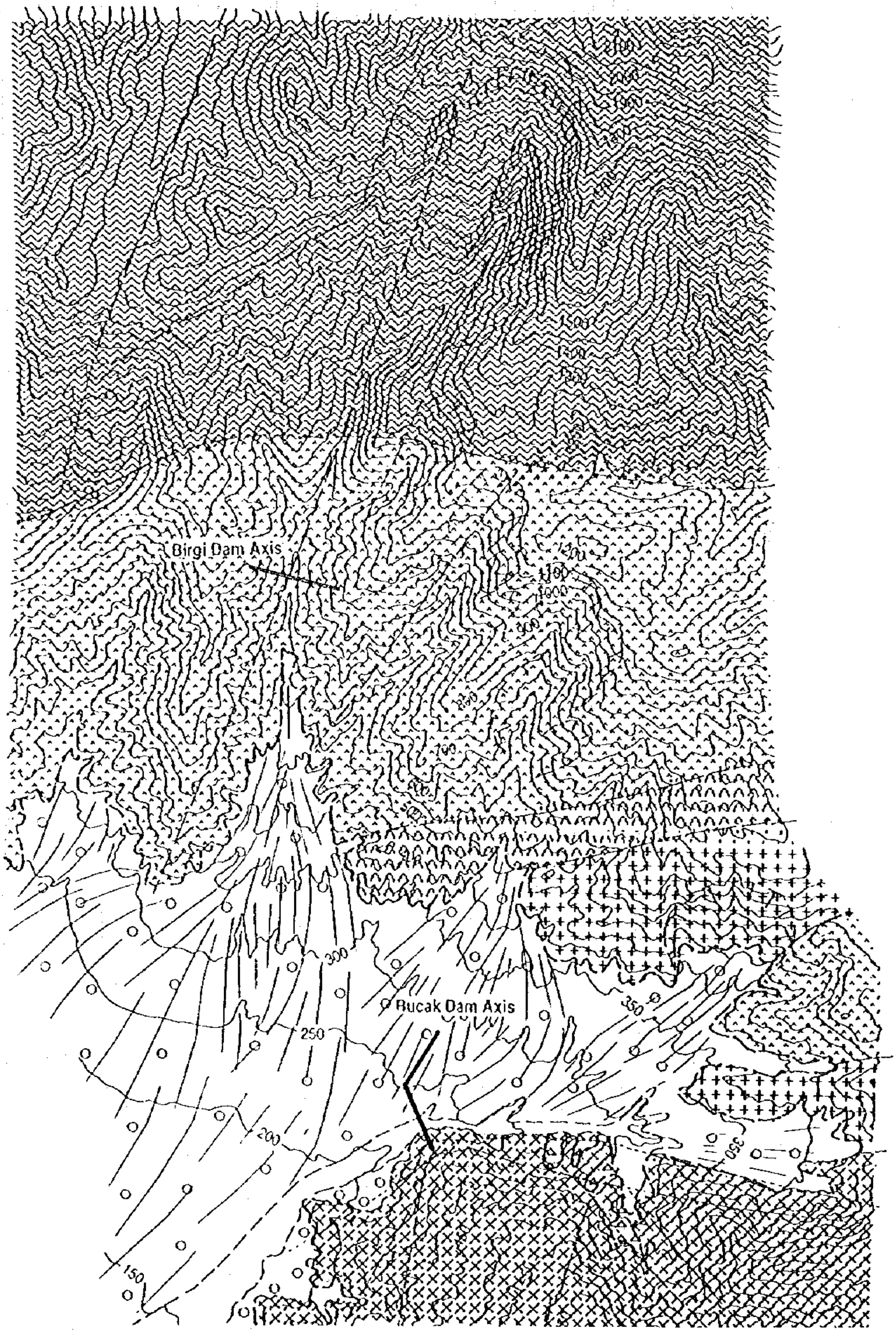
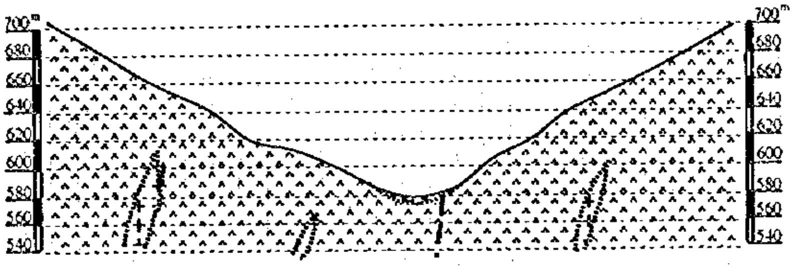
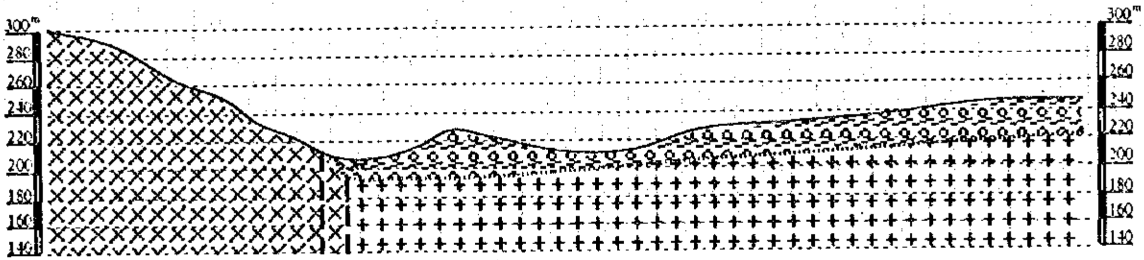


Figure-B.4(1) Geological Map around Birgi & Bucak Dam Axes (Scale 1/50,000)



Geological Profile along Birgi Dam Axis

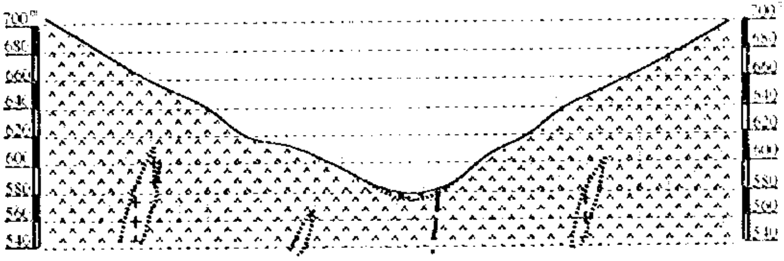


Geological Profile along Bucak Dam Axis

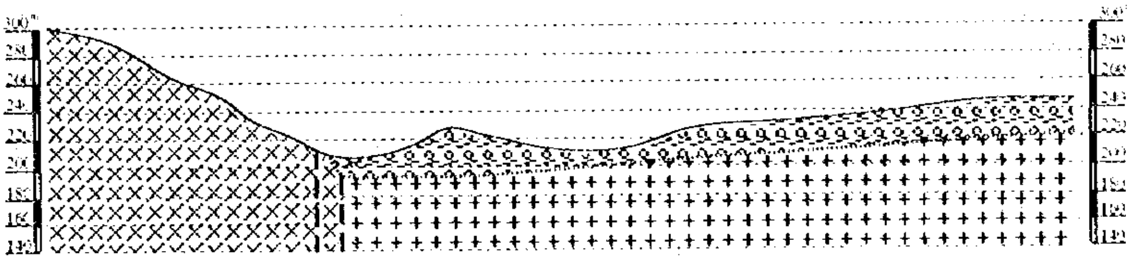
Legend

River DEposit
Slope Debris
Alluvial Fan Deposit
Mica Schist
Leptite ~ Biotite Schist
Gneiss, Schist Undifferentiated
Augen Gneiss
Granit
Amphibolite
Geological Boundary
Lineament (Infered Fault)
Land-slided Area

Figure-B.4(2) Geological Profile along Birgi & Bucak Dam Axes (Scale 1/5,000)



Geological Profile along Birgi Dam Axis



Geological Profile along Bucak Dam Axis

Legend

▨ River DEposit
▨ Slope Debris
▨ Alluvial Fan Deposit
▨ Mica Schist
▨ Leptite ~ Biotite Schist
▨ Gneiss, Schist Undifferentiated
▨ Augen Gneiss
▨ Granit
▨ Amphibolite
⋰ Geological Boundary
⋰ Lineament (Infered Fault)
⌒ Land-slided Area

Figure-B.4(2) Geological Profile along Birgi & Bucak Dam Axes
(Scale 1/5,000)

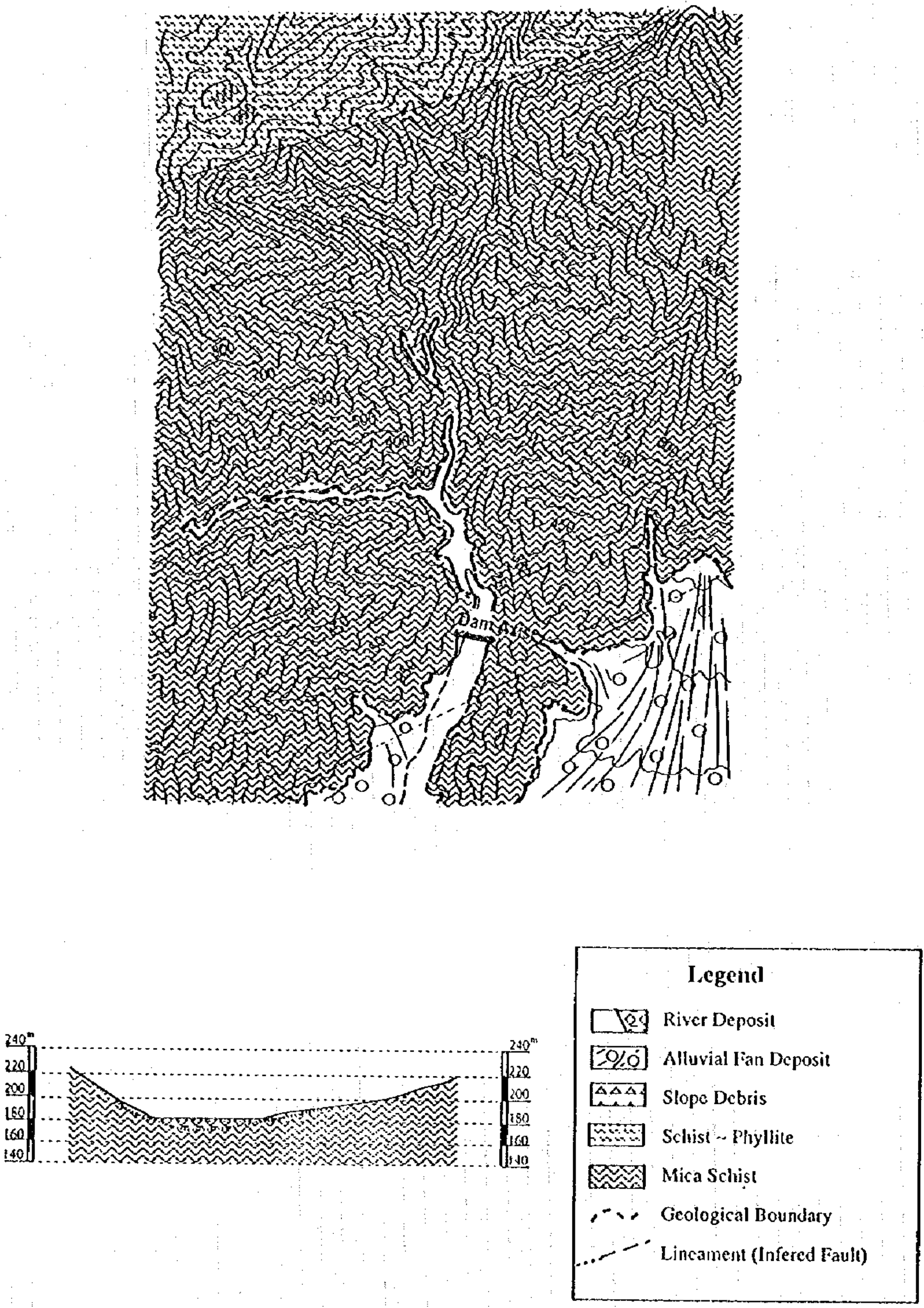


Figure -B.5
Geological Map around the Ödemiş Dam Site (Scale 1/50,000)
and Geological Profile along Dam Axis (Scale 1/5,000)

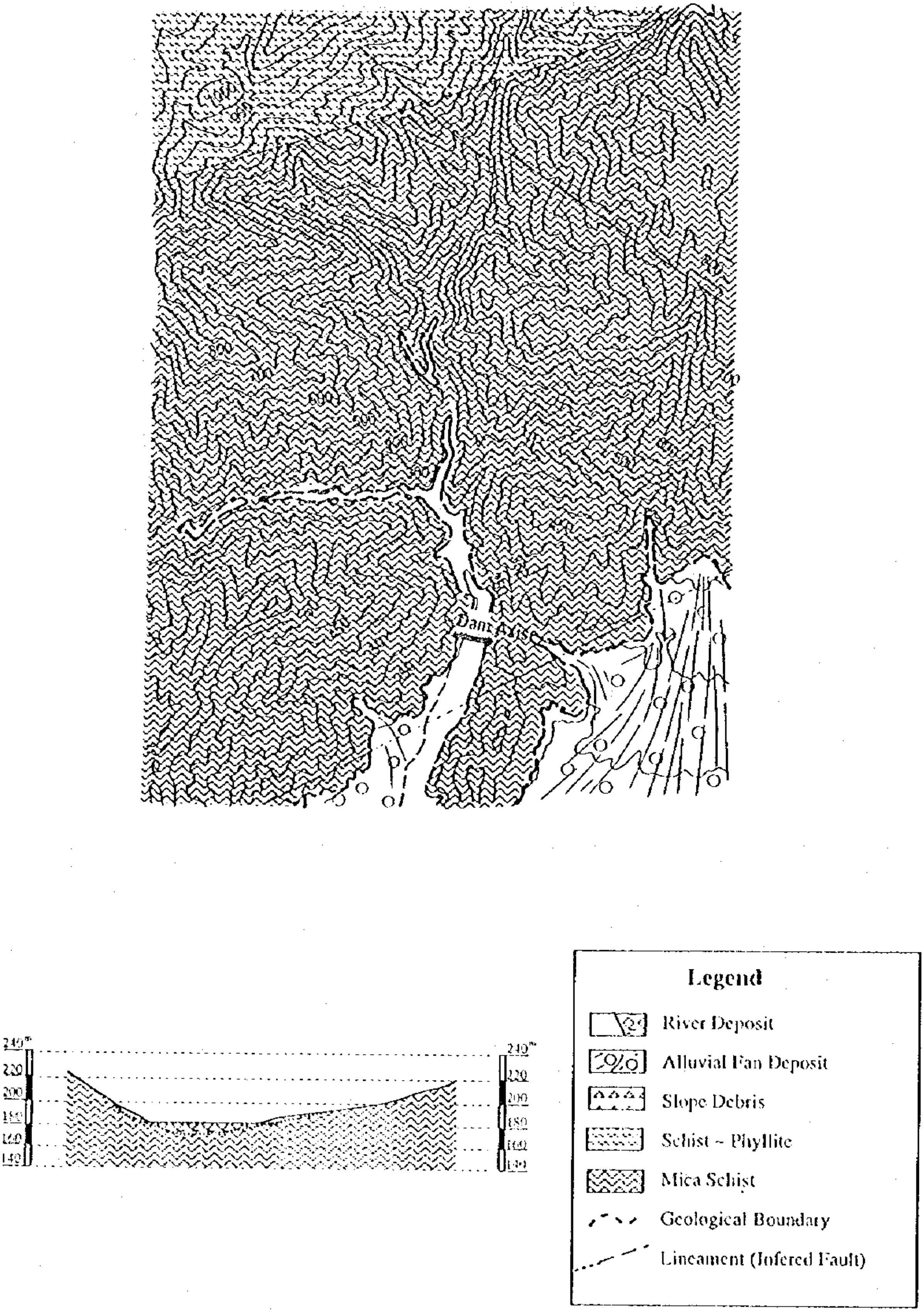


Figure -B.5
Geological Map around the Ödemiş Dam Site (Scale 1/50,000) and Geological Profile along Dam Axis (Scale 1/5,000)

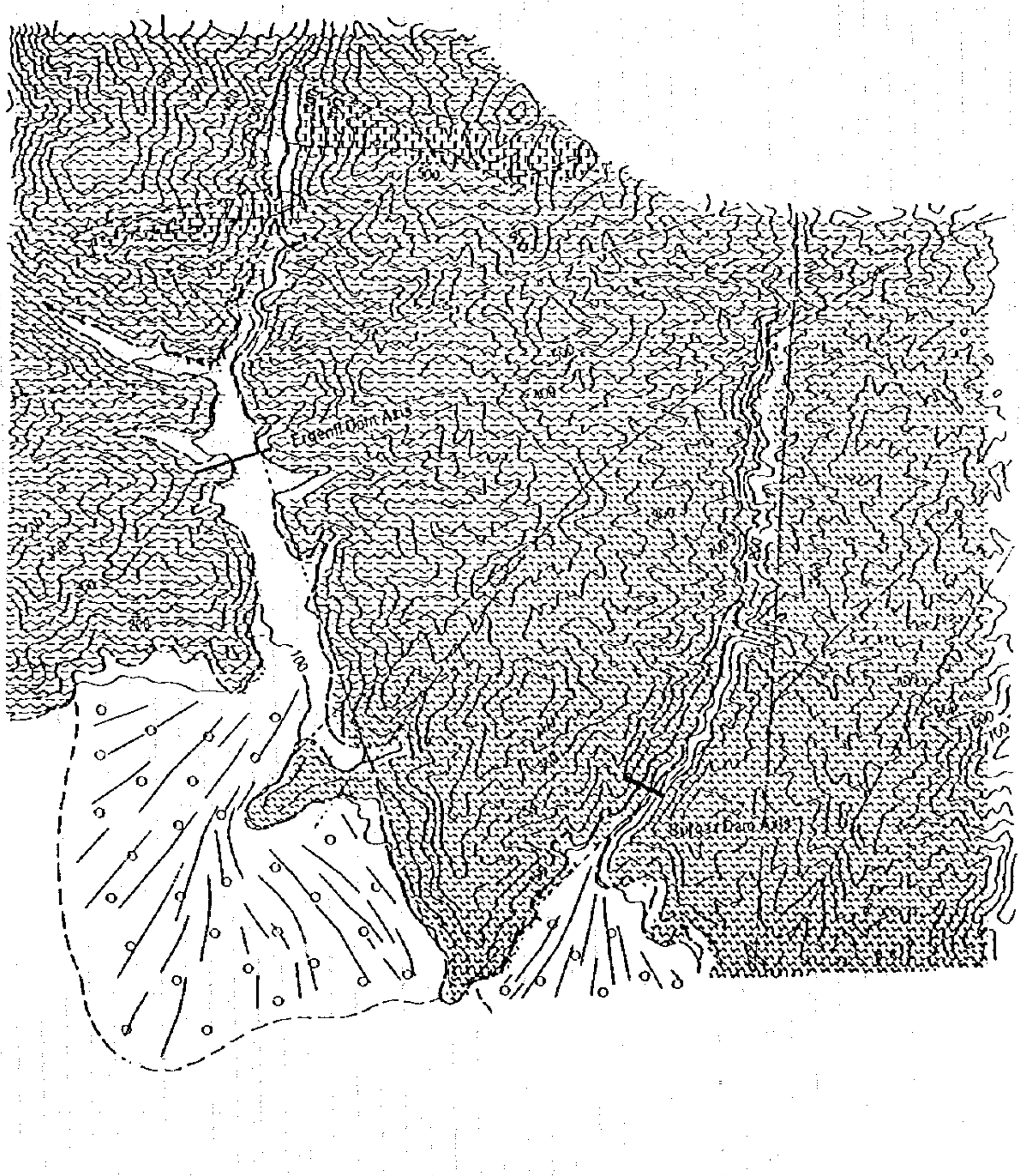


Figure-B.6(1) Geological Map around Ergenli & Burgaz Dam Axes (Scale 1/50,000)

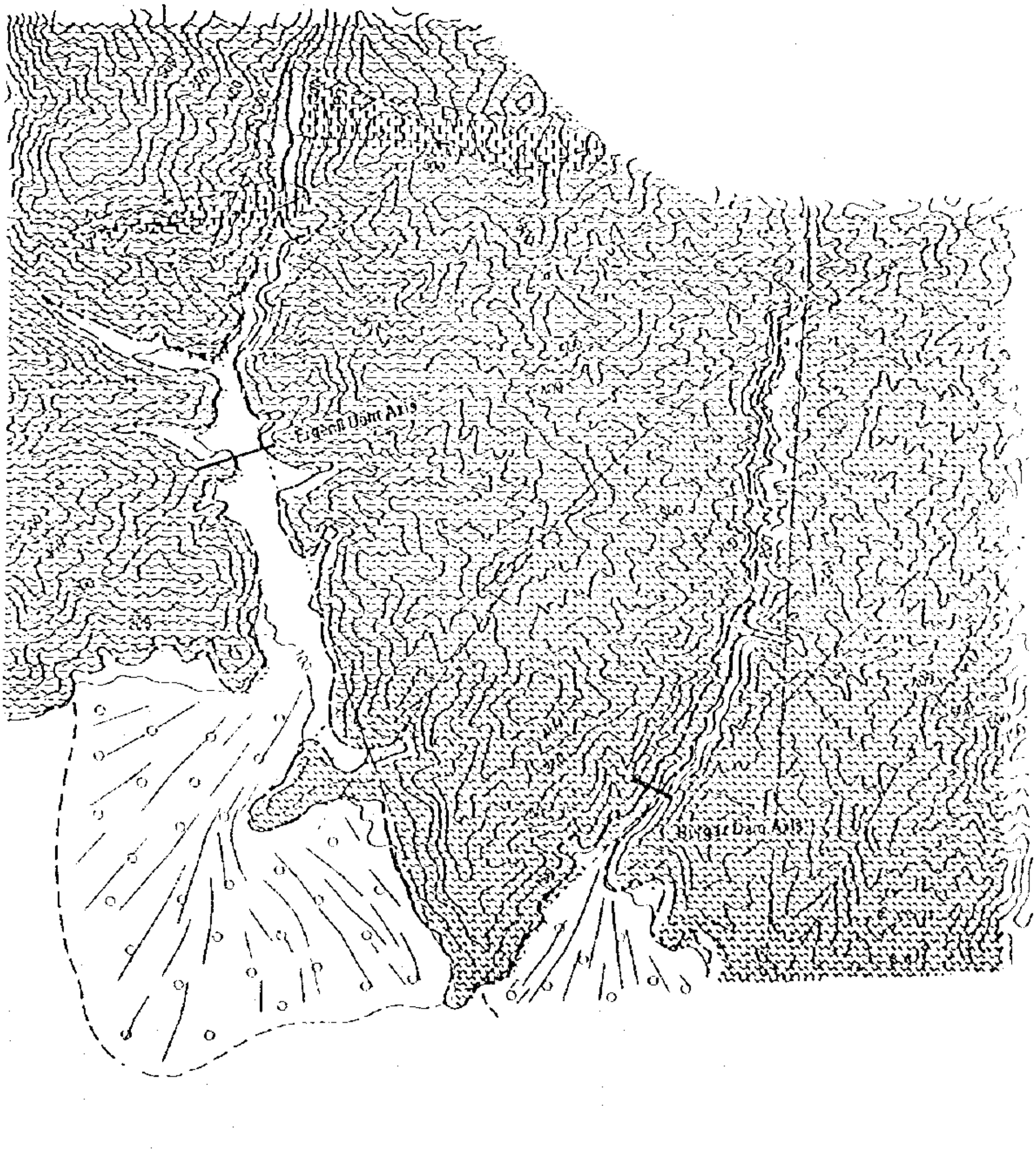
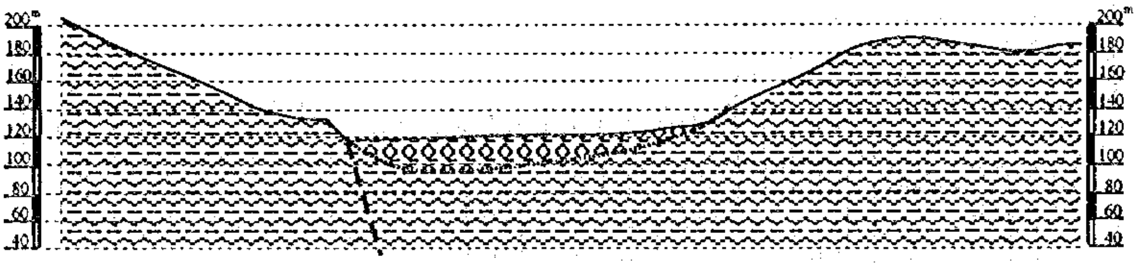
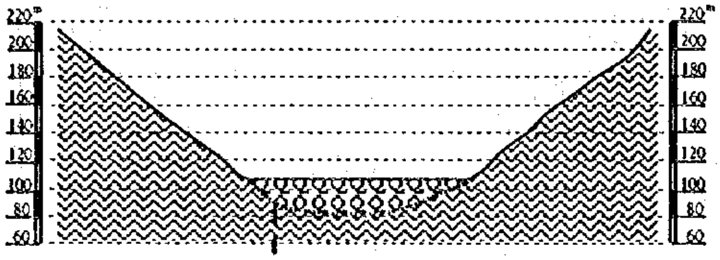


Figure-B.6(1) Geological Map around Ergenli & Burgaz Dam Axes
(Scale 1/50,000)



Geological Profile along Ergenli Dam Axis

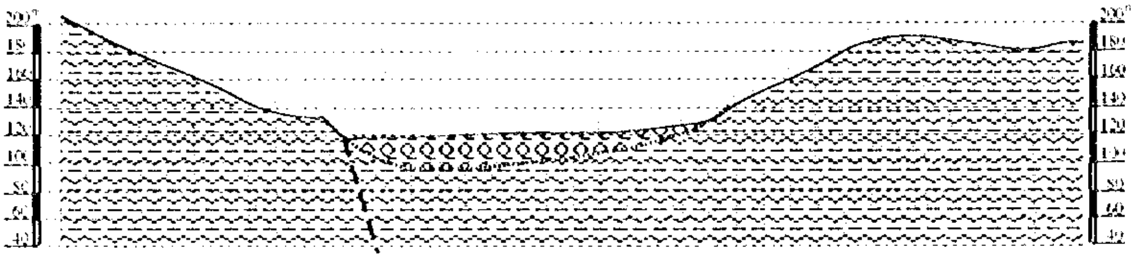


Geological Profile along Burgaz Dam Axis

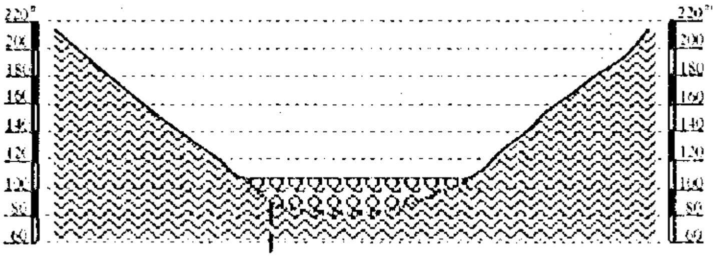
Legend

- ▨ Alluvium
- ▨ Alluvial Fan Deposit
- ▨ Marble
- ▨ Phillite, Mica-Quartz Schist
- ▨ Mica Schist
- ‐ ‐ ‐ Geological Boundary
- ‐ ‐ ‐ Lineament (Infered Fault)
- ∩ Land-slided Area

Figure-B.6(2) Geological Profile along Ergenli & Burgaz Dam Axes (Scale 1/5,000)



Geological Profile along Ergenli Dam Axis



Geological Profile along Burgaz Dam Axis

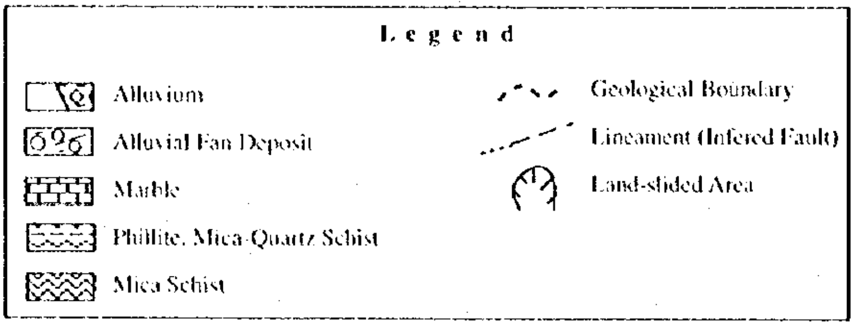


Figure-B.6(2) Geological Profile along Ergenli & Burgaz Dam Axes
(Scale 1/5,000)

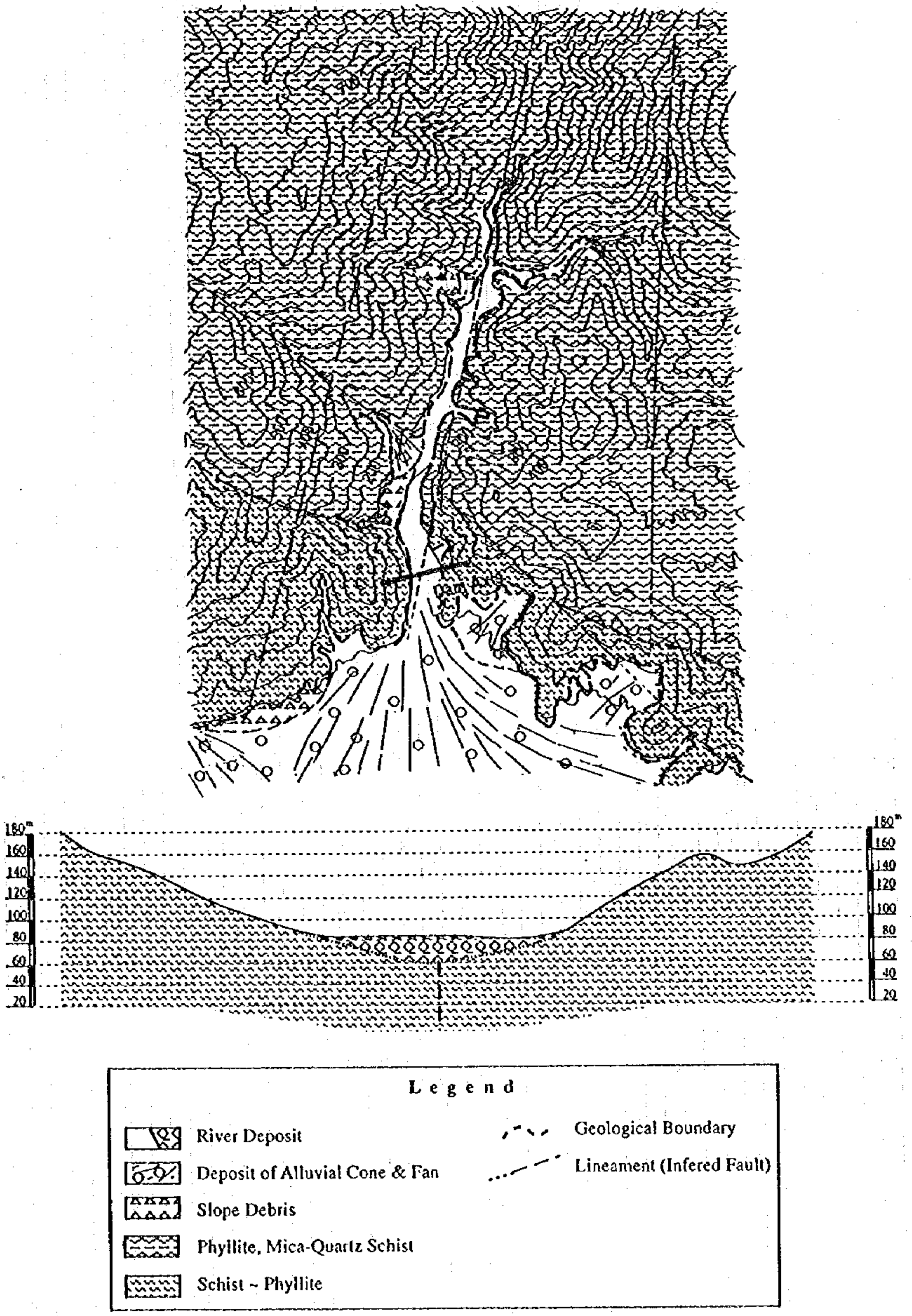


Figure -B.7
Geological Map around the Uladi Dam Site (Scale 1/50,000)
and Geological Profile along Dam Axis (Scale 1/5,000)

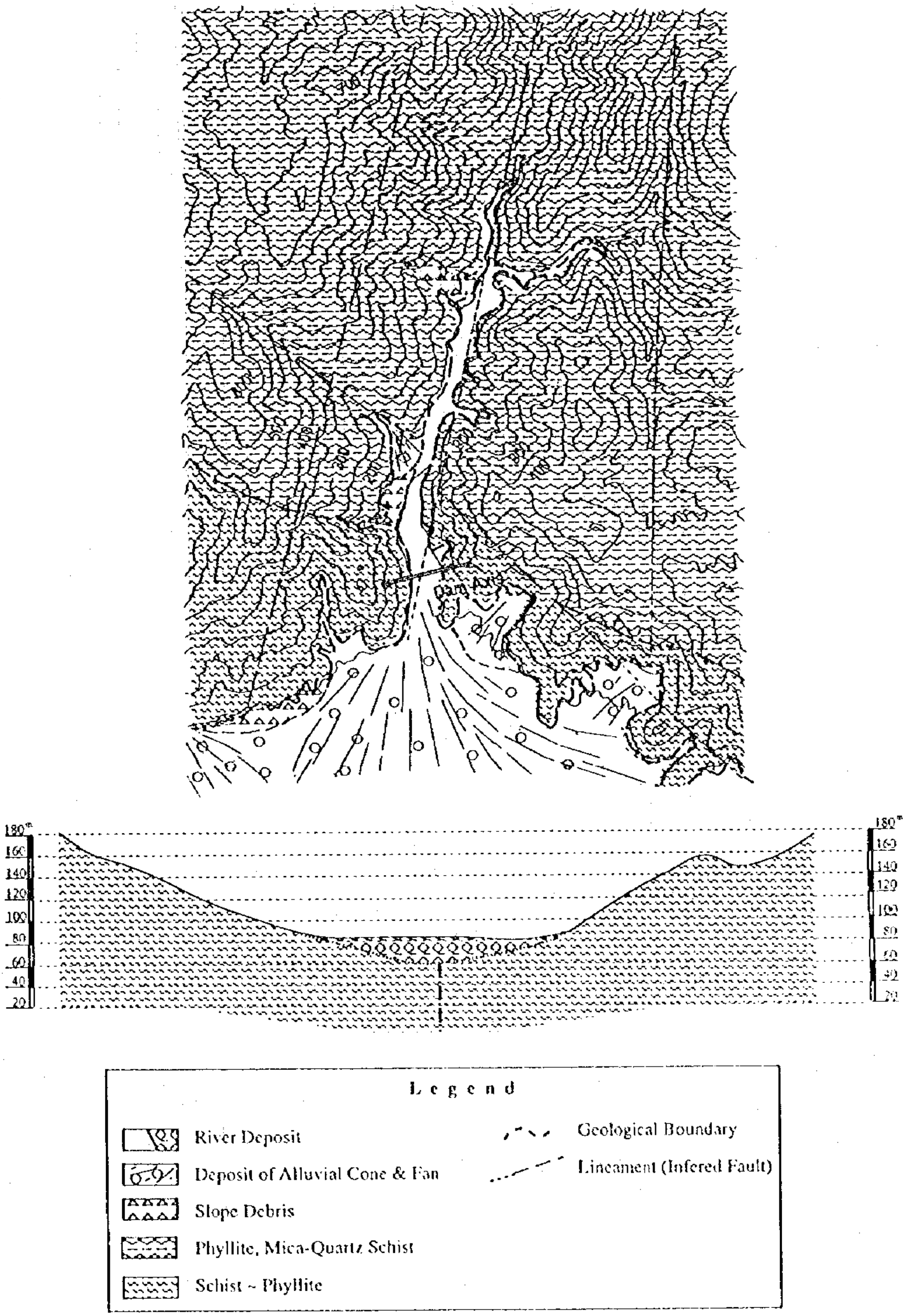
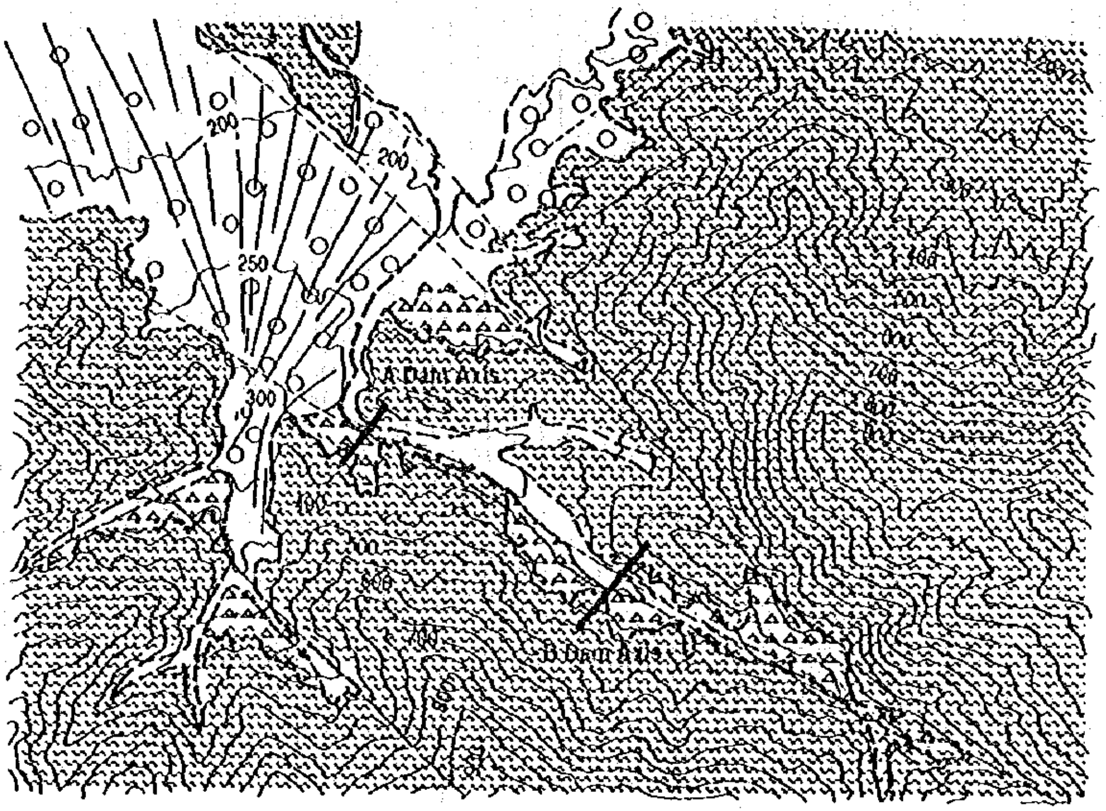
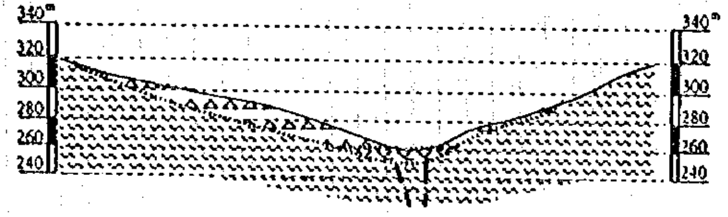


Figure -B.7
Geological Map around the Uladı Dam Site (Scale 1/50,000)
and Geological Profile along Dam Axis (Scale 1/5,000)

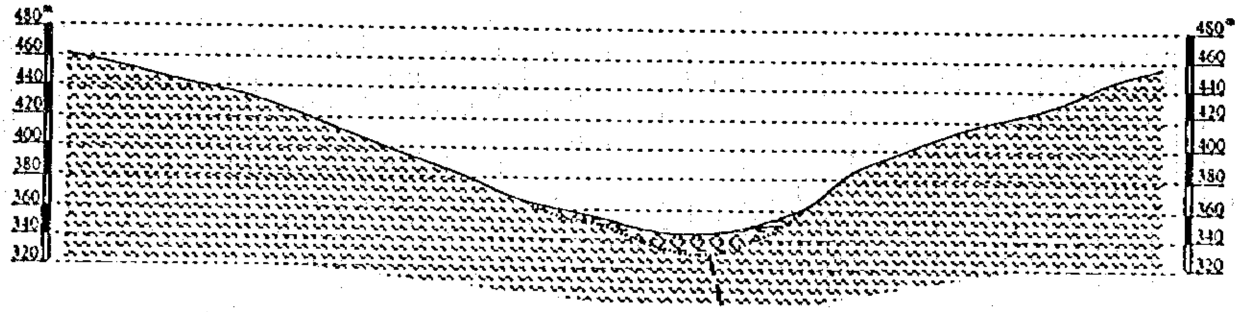




Geological Profile along A Dam Axis

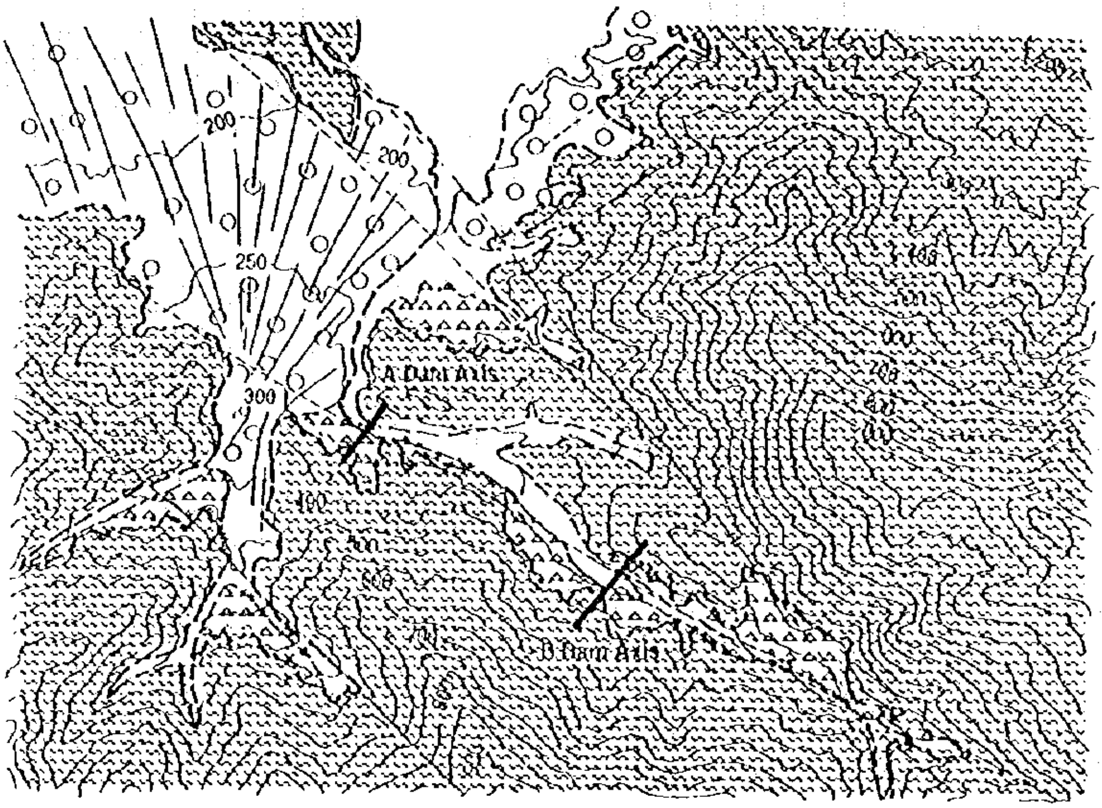
Legend

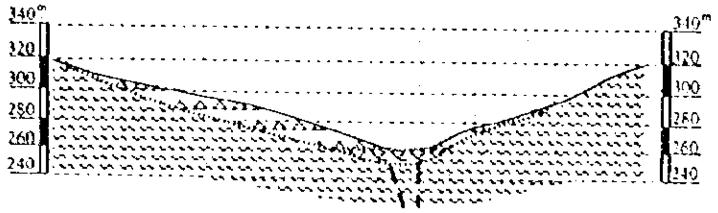
- Alluvium
- Deposit of Alluvial Cone & Fan
- Talus Deposit
- Schist ~ Phyllite
- Geological Boundary
- Lineament (Infered Fault)



Geological Profile along B Dam Axis

Figure -B.8
Geological Map around the Pirinççi. Dam Site (Scale 1/50,000) and Geological Profile along Dam Axis (Scale 1/5,000)

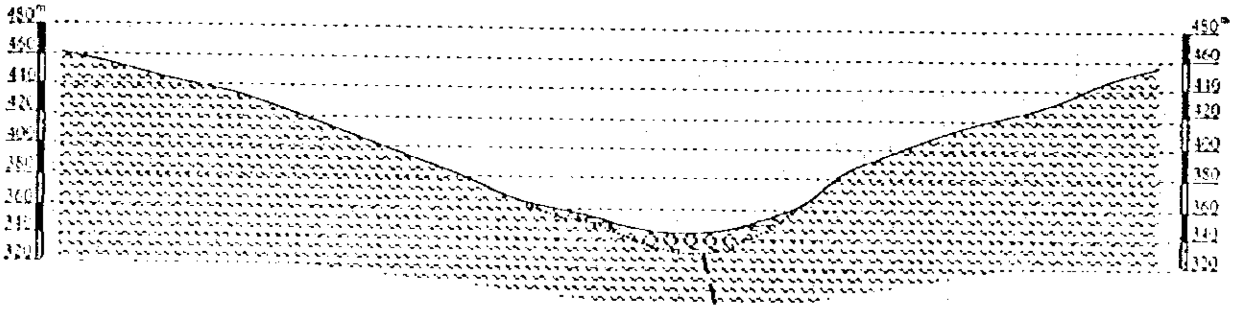




Geological Profile along A Dam Axis

Legend

- ▢ Alluvium
- ○ Deposit of Alluvial Cone & Fan
- △ Talus Deposit
- ▨ Schist ~ Phyllite
- Geological Boundary
- Lineament (Infered Fault)



Geological Profile along B Dam Axis

Figure -B.8
Geological Map around the Pirinççi. Dam Site (Scale 1/50,000)
and Geological Profile along Dam Axis (Scale 1/5,000)

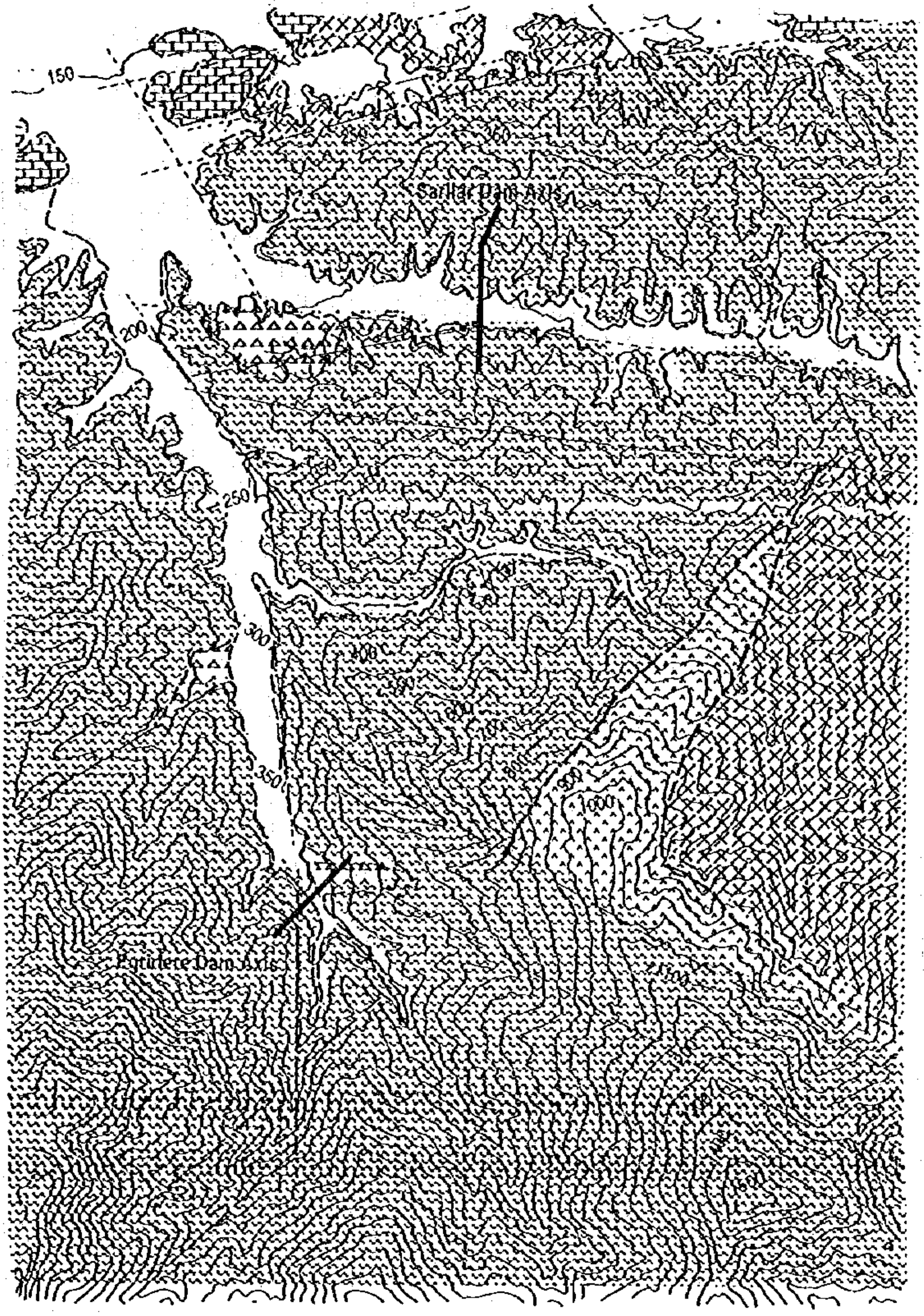


Figure-B.9(1) Geological Map around Sarilar & Eğridere Dam Axes (Scale 1/50,000)

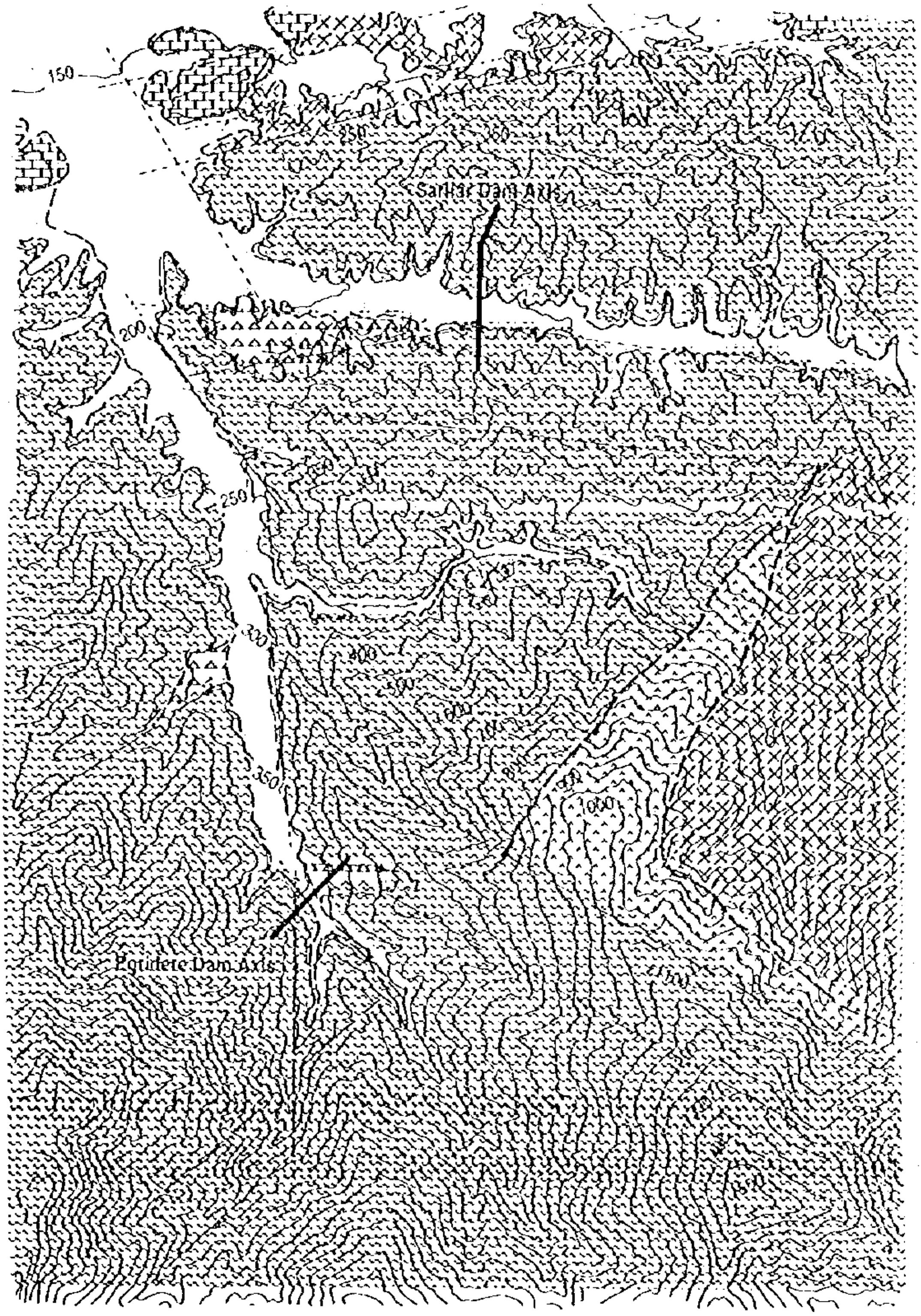
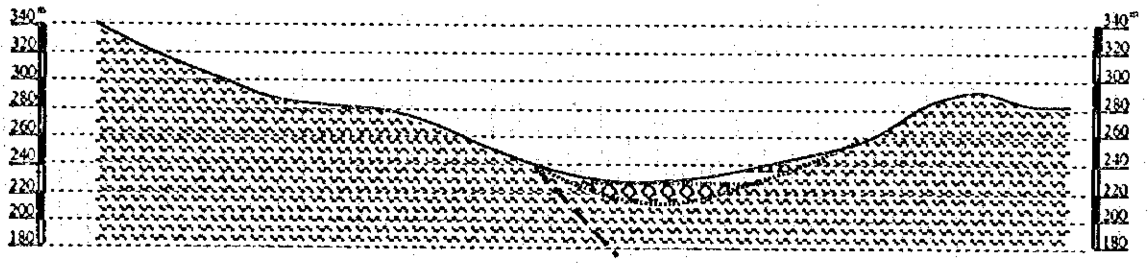
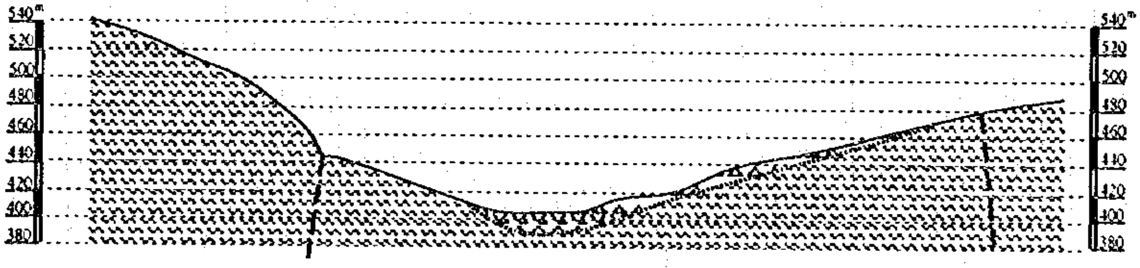


Figure-B.9(1) Geological Map around Sarilar & Eğridere Dam Axes (Scale 1/50,000)



Geological Profile along Sarilar Dam Axis



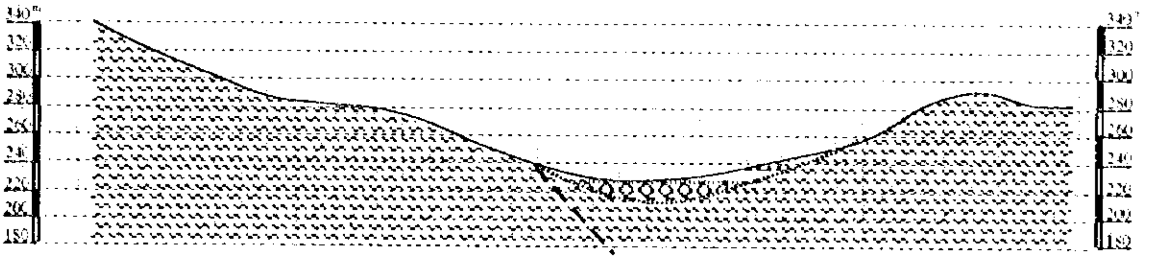
Geological Profile along Eğridere Dam Axis

Legend

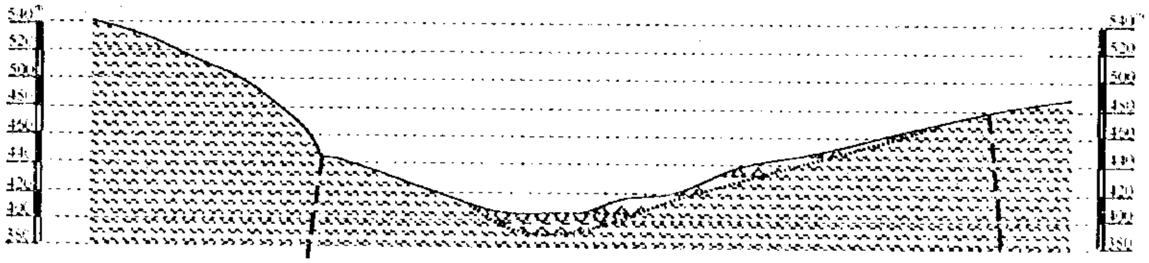
Alluvium
Slope Debris
Schist ~ Phyllite
Marble
Leptite ~ Biotite Schist
Gneiss

Geological Boundary
Lineament (Infered Fault)
Land-slided Area

Figure-B.9(2) Geological Profile along Sarilar & Eğridere Dam Axes
(Scale 1/5,000)



Geological Profile along Sarilar Dam Axis



Geological Profile along Eğridere Dam Axis

Legend

▨	Alluvium	⋰	Geological Boundary
△	Slope Debris	⋯	Lineament (Infered Fault)
▤	Schist ~ Phyllite	⌒	Land-slided Area
▦	Marble		
▵	Leptite ~ Biotite Schist		
☒	Gneiss		

Figure-B.9(2) Geological Profile along Sarilar & Eğridere Dam Axes (Scale 1/5,000)

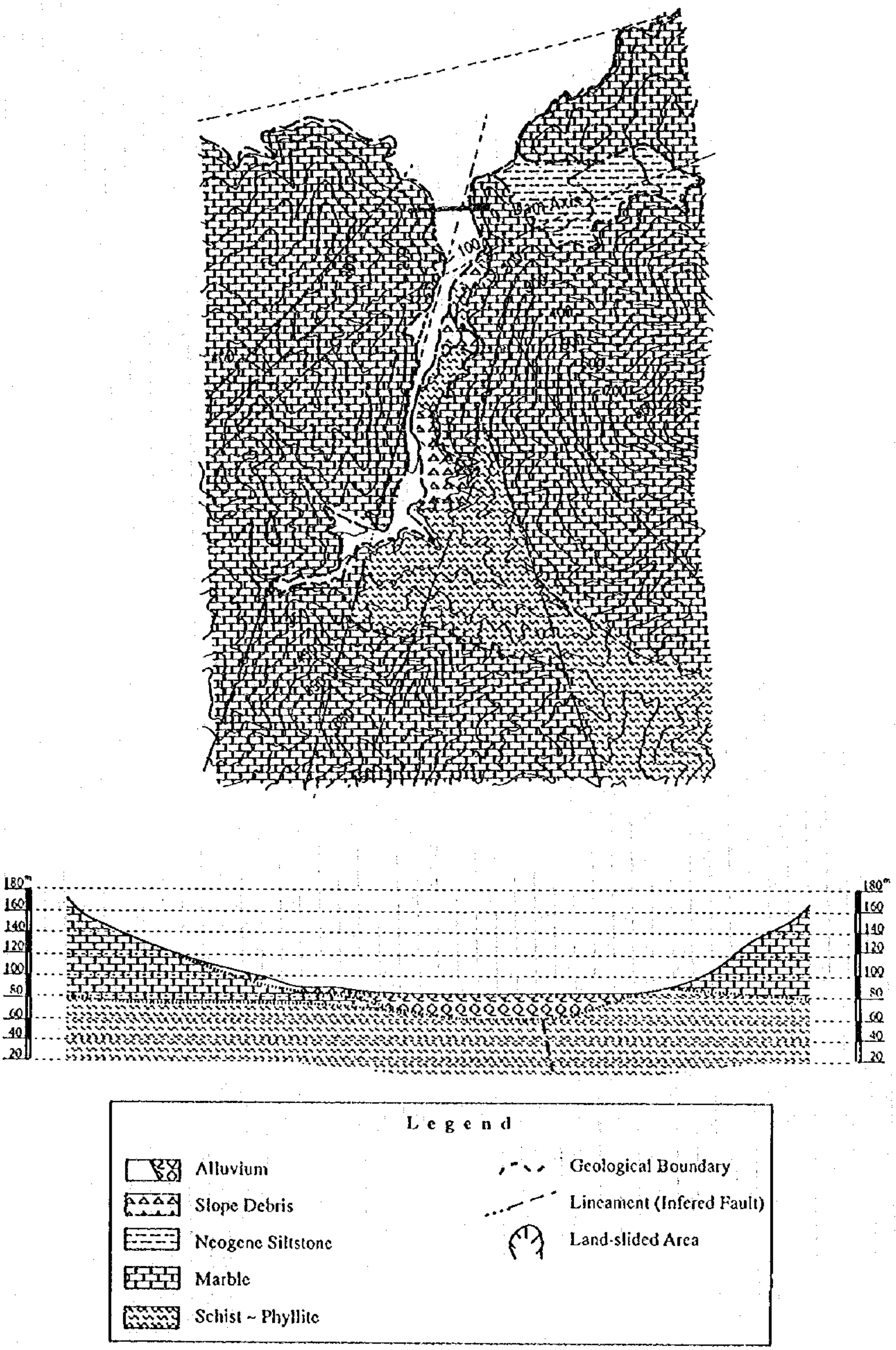


Figure -B.10
Geological Map around the Akyurt Dam Site (Scale 1/50,000) and Geological Profile along Dam Axis (Scale 1/5,000)

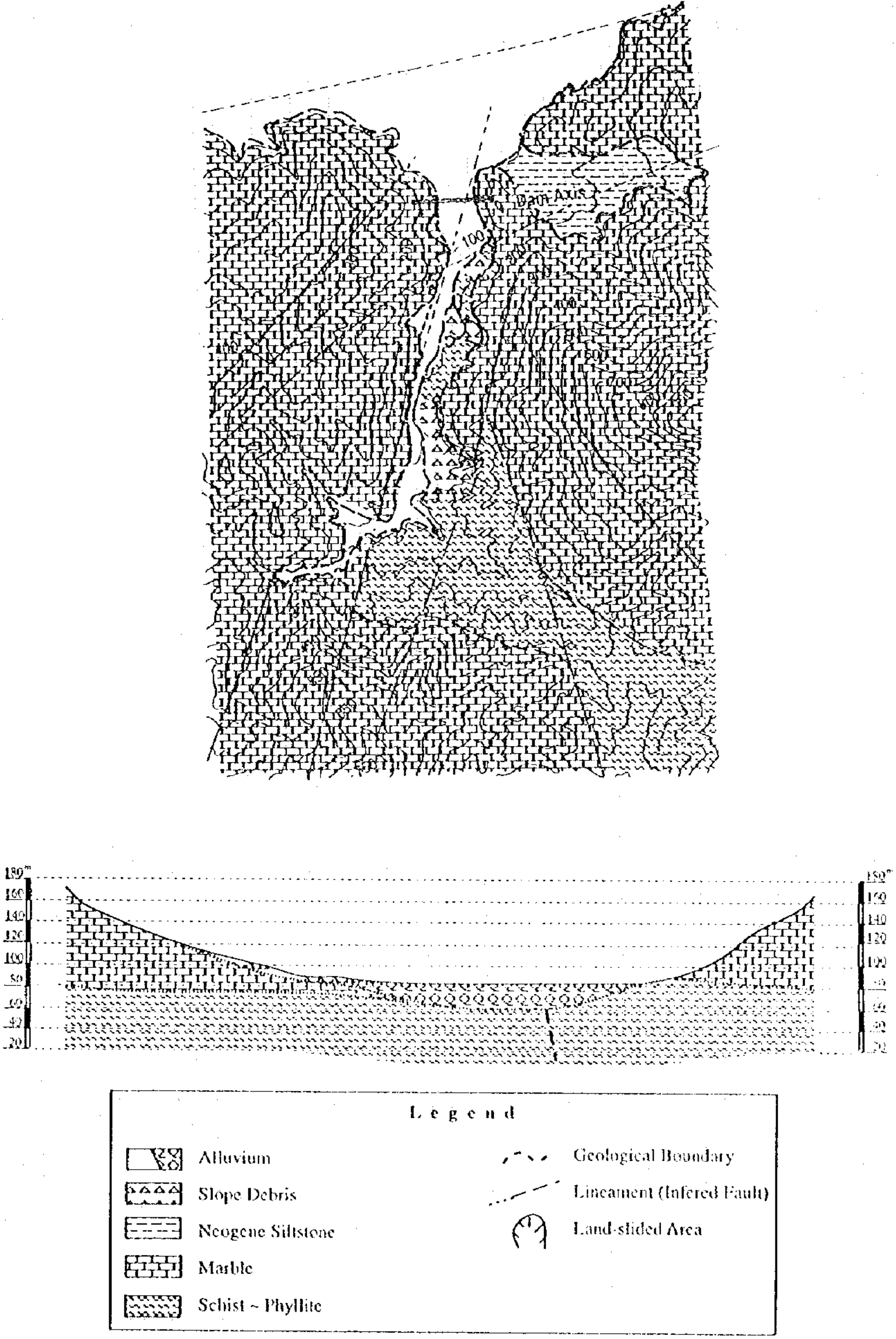


Figure -B.10
Geological Map around the Akyurt Dam Site (Scale 1/50,000) and Geological Profile along Dam Axis (Scale 1/5,000)

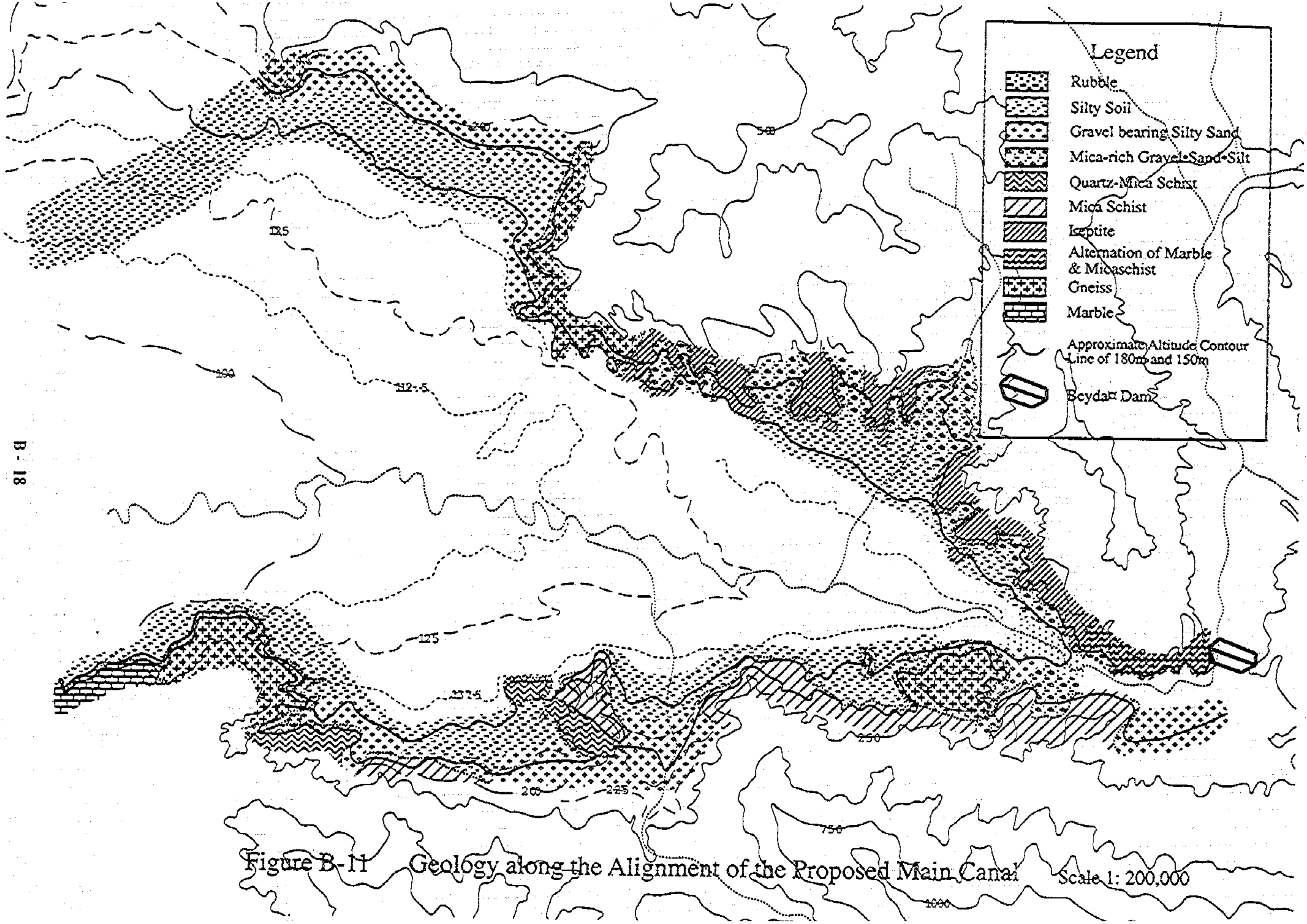


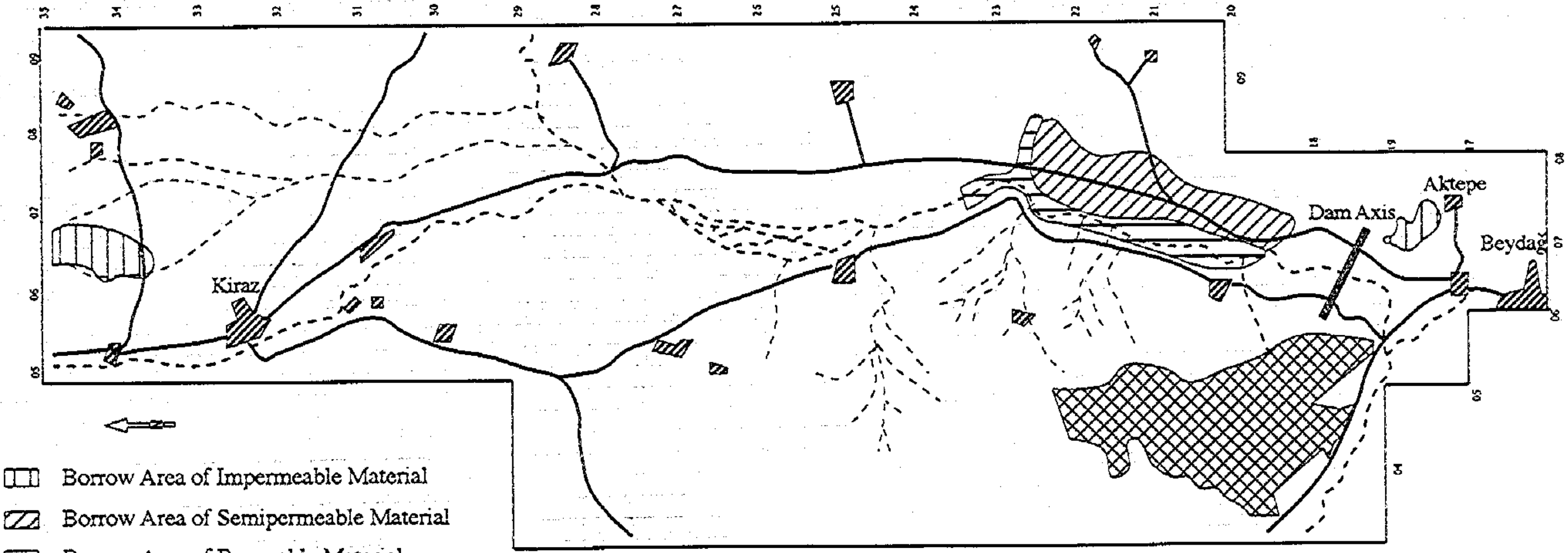
Figure B-11 Geology along the Alignment of the Proposed Main Canal Scale 1: 200,000

•Beydağ Dam

Design Embankment Volume 9.0 MCM

	Volume of Storage	Location	Soil Classification	LL	PL	PI	Clay • Silt	Sand	Gravel	Remarks
Impermeable Material	2.4 MCM	North of Kiraz and Near around Beydağ Aktepe	GM - ML SM - SC, CL	21 ~ 34%	-	10 ~ 24%	18 ~ 50%	40 ~ 60%	10 ~ 22%	-
Semipermeable Material	7.0 MCM	In the Reservoir Area	CL - ML	21 ~ 29%	-	3 ~ 13%	10 ~ 50%	30 ~ 70%	5 ~ 20%	-

	Volume of Storage	Location	Soil Classification	Specific Gravity	Water Absorption	Abrasion Loss	Clay • Silt	Sand	Gravel	Remarks
Permeable Material	8.6 MCM	In the Reservoir Area	SM - SC GP - SP	-	-	-	0 ~ 3%	30 ~ 55%	50 ~ 60%	-
Rock Material	30 MCM	In the Hill of Right Bank Side of Dam Axis	-	2.66 ~ 2.68	0.32 ~ 0.54%	35.6 ~ 36.2%	-	-	-	Marble Quarry



▥ Borrow Area of Impermeable Material

▨ Borrow Area of Semipermeable Material

▤ Borrow Area of Permeable Material

▩ Quarry site of Rock Material and/or Aggregate

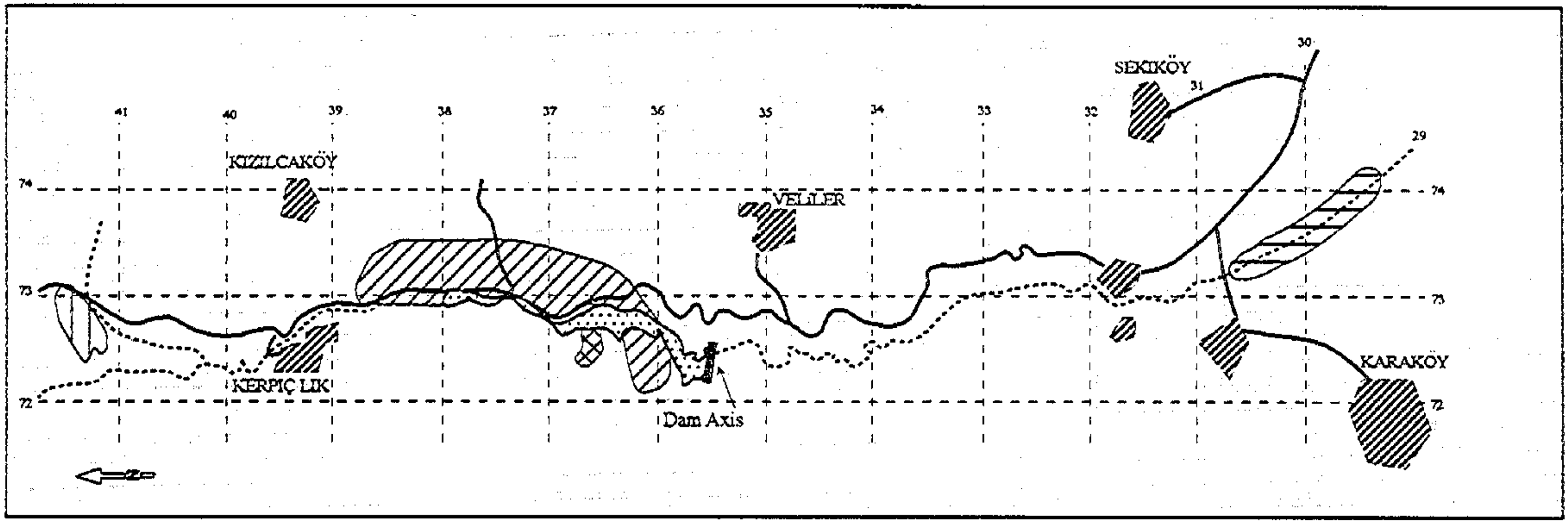
Figure B-12 Locations of Borrow Area & Quarry Site for Embankment Materials & Aggregate and Their Main Physical Properties for Beydağ Dam

•Aktaş Dam

Design Embankment Volume 1.6 MCM

	Volume of Storage	Distance from Dam Site	Soil Classification	Gravel Including Ratio	Maximum Grain Size	LL	PL	PI	Max. Dry Density	Opt. Moisture Content
Impermeable Material	1.1 MCM	Northward about 6km	CL	10~50% (mean15Å`30%)	3"~5" (mean 1.5")	30~50%	20~25%	12~25%	1.75~ 1.95g/cm3	11~18%
Semipermeable Material	6.0 MCM	Upstream Side of Left Bank	GM~SM~ML	15~55% (mean20~40%)	3"~5"	22~30%	18~26%	2~5%	1.82~ 1.95g/cm3	11~14%

	Volume of Storage	Distance from Dam Site	Specific Gravity	Water Absorption Ratio	Abrasion Loss	Apparative Porosity
Permeable Material	1.1 MCM	Southward about5~6km	2.60~2.67	Sand,1.3~2.5% Gravel,0.9~1.3%	38.5~42.0%	-
Rock Material	1.5 MCM	Northward about 1km	2.75	0.66%	33.40%	1.76%



▭ Borrow Area of Permeable Material

◫ Borrow Area of Impermeable Material

⊠ Quarry site of Rock Material and/or Aggregate

▨ Borrow Area of Semipermeable Material

Figure B-13 Locations of Borrow Area & Quarry Site of Embankment Materials & Aggregate and Their Main Physical Properties for Aktaş Dam

ANNEX C

HYDROGEOLOGY

ANNEX C

GEOHYDROLOGY

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ANNEX C

HYDROGEOLOGY

1 Present Conditions

(1) Küçük Menderes River Basin (Master Plan Study Area)

The alluvial groundwater basin of the Küçük Menderes River Basin is shown on the Figure-C.1 as the altitude contour map of alluvial bottom plane. This map was made based on the depth contour map of alluvial bottom plane made by DSİ in 1968. It is understandable from the figure that the groundwater basin in the alluvial strata is composed mainly of Ödemiş-Tire & Bayındır-Torbalı basins.

Figure-C.1 shows also the location of observation wells. The hydrogeological parameters of aquifer checked at respective observation wells through pumping tests are listed in Table-C.1.

From these results, the groundwater basin is divided into six as shown in Figure-C.2 which also shows the general distribution of permeability in the two main basins, Ödemiş-Tire & Bayındır-Torbalı.

Figure-C.3 shows the altitude of groundwater table as of 1992 and the hydraulic gradient along main channel. The profile along the main channel is as shown in Figure-C.4. Figure-C.6 shows the fluctuation of groundwater table checked once a month approximately at respective observation wells as time series.

Groundwater table rises and falls in one year cycle, though the amplitude of vibration is different from respective wells. The whole trend of groundwater table fluctuation can be said generally as the followings:

(i) The groundwater table was relatively stable until 1985 and started falling gradually from 1985 on.

(ii) The ratio of falling down from 1989 has become larger than the before.

Decrease of precipitation and recharge caused the lowering of groundwater table from 1985, besides further lowering has been caused from 1989 due to over pumping for irrigation. The reasons are as follows:

(i) The falling down of groundwater table in the irrigation season is becoming surely remarkable after 1989.

(ii) Though the precipitation from 1989 had the trend a little lower than the before, the affection by pumping up through wells for irrigation etc. is much bigger than the decreasing of precipitation. Of course that is why the shortage of precipitation needs more pumping up from the groundwater.

Figure-C.7 and C.8 show the locations of existing wells in the Küçük Menderes Plain which are mainly identified based on the topographic maps published in 1960 ~ 1964 and 1979 ~ 1980.

(2) Beydağ-Ödemiş Area (F/S Area)

The Study Team conducted inventory survey on the existing wells in the Project Area for the items of number of well, their locations and types, diameter of outlet pipes, power sources, working conditions, and covering area of irrigation etc. As a result, it becomes clear that wells over than 2,000 exist in this area.

Table-C.2 shows the number of wells, water allocation, and covering area of irrigation at each köy distinguishing private and cooperative registered at DSİ. While, Figure-C.9 to C.18 show the survey result of existing wells' for their numbers and the covering area of irrigation in every of 1km^2 of area.

As of March 1995, DSİ has allocated about 19 MCM of the water right to 654 wells for private use, and a little more than 11 MCM to 35 wells for cooperative use in the Beydağ and Ödemiş districts. The Study Area is included in these districts. The cooperative Konaklı is newly established. According to the data, average annual water pump-up volume per one well is about 29,000 m^3 in the case of private wells, while a cooperative well pumps up about 324,000 m^3 per annum and irrigates about 34 ha.

As a result of existing wells' surveys in this phase, 2,278 wells were confirmed, among of which 59 wells were already closed, then 2,219 wells are working now. Among them, 75 wells were not identified for their covering areas of irrigation, 10 wells were DSİ use for cooperatives, 9 wells were İllers Bank use for drinking purpose, 28 were for private drinking use, and 2 were for factory use. The following mention is the summarize the above. When calculating the total pump-up volume of groundwater in the Beydağ-Ödemiş Area, the allocated average yields in the respective köys were calculated first based on the data shown in Table-C.2, and those respective volumes were multiplied by the number of wells existing in the respective areas confirmed from the existing wells' survey carried out in this phase. Then, the quantity of pumped groundwater would amount to 40 MCM per annum in total for the private use. As a result, adding the quantity of cooperative use (annually 11 MCM), the total yields in the Study Area would amount to 51 MCM per annum.

Also according to the above survey result, the power source of the well is electricity for 89.5% of the total wells. The remaining wells are still operated by engines, which are mainly located along Küçük Menderes River, because no electricity has been supplied there.

Figure-C.11 shows the contour map of alluvium bottom plane which was modified from the materials for the study on the hydrogeology of Küçük Menderes River Plain carried out by DSİ in 1968. Figure-C.12 to C.22 show the well's distribution, and groundwater table distribution in the Study Area, which were prepared based on the result of existing wells' surveys in the Study period.

Basically the alluvium fills the gravens of the Menderes Massif formed by the tectogenesis. Their main underground physiography is shaped by many faults. As shown in the Figure-C.11, it has largely such two basins as that around Beydağ - Kaymakcı and around Ödemiş. These basins are the part of the aforesaid Ödemiş - Tire Groundwater Basin. The thickness of alluvium in the former basin is a little more than 100 m, and more than 250 m in the latter basin at the maximum.

As shown in Figure-C.9 and C.20, private wells concentrate mainly around Mescitli and Yeğenli where wells density is more than 30 per 1 km^2. The wells have also been concentratedly drilled in both bank side areas along Küçük Menderes river mainly between Beydağ town and the north of Konaklı town (20 ~ 30 wells /km^2). Further from the Ovakent - Ödemiş Road to the downstream side, they have a density of around 10 wells per 1 km^2. Figure-C.13 and C.22, show the groundwater table below the ground surface and its altitude. These information were mainly collected through the inquiry to farmers. The depth of groundwater table is usually around 20 m to 25 m below the ground surface along Küçük Menderes River, but as apart from the river, it becomes deeper gradually, and around Ödemiş town it reaches more than 40 m.

As to the drawdown of groundwater table from the early days (before 1985) up to date, one example is shown in the Figure-C.5 (2) which shows the section of the middle reaches of Ödemiş-Tire Groundwater Basin. Until 1992, the tendency of the drawdown of groundwater table is remarkable along the foot slope from the mountain to the plain reaching the drawdown to 30 to 40 m. However, the drawdown along the Küçük Menderes river is not so big comparing to that along the foot slope. This may be because of that the less recharge of groundwater caused by draught created the less hydrodynamic gradient.

On the other hand, recently the drawdown along the Küçük Menderes river becomes remarkably bigger; 20 to 25 m, which may be caused by remarkable increase of pumping up of groundwater through wells in the plain area near the river. In other area also, the same tendency has been observed.

(3) Geothermal Zone, Boron and Groundwater

From the view point of boron hazards against agricultural crops, the studies on the boron including ratio in the groundwater in the Gedis river basin have been carried out by DSİ since three years while the studies in the Küçük Menderes river basin have been started this year.

In general the saline water includes relatively high ratio of boron, so that marine sediments may include it at relatively high level. Besides, since the boron is also one of rare elements usually with silicate minerals, it is produced sometimes accompanied by pneumatolytic gas or hydrothermal fluid originated from descent liquid of acidic magma namely with hydrothermal springs. In both cases, it puts out as borate and/or boracic to meta-boracic acid.

Typical temperature of hydrothermal springs is over than 100°C in the Büyük Menderes river basin, and from 75°C to 100°C in the Gedis river basin. On the other hand, that in the Küçük Menderes river basin is in between 20°C and 45°C. Comparing to the Büyük Menderes river basin and the Gedis river basin, the temperature of hydrothermal springs in the Küçük Menderes river basin is fairly lower, then it may be relatively less affected by the geothermal effect.

Figure-C.15 shows the relationship between the temperature and the boron including ratio of groundwater studied in the Gedis river basin and the Küçük Menderes river basin. Although the relationship is not clear, the most of all groundwater belongs to the extent A. Those having relatively high temperature over 28°C or high including ratio of boron over 3 ppm are only found in the upstream to midstream areas of Gedis river basin (Salihli ~ Alaşehir) at sporadically limited area seemingly with subsurface tectonic structure easily springing out the hydrothermal fluid and/or pneumatolytic gas. Even in the extent A, though those in the Gedis river basin reach around 2 ppm of boron including ratio, those in the Küçük Menderes river basin show usually fairly lower having values mostly less than 1 ppm.

Figure-C.16 shows the temperature (and the sampling depth), the boron including ratio of groundwater and their locating distribution in the Küçük Menderes river basin. In case the recharge of groundwater is few in a long drought period, the content of groundwater may be less diluted resulting in the density being relatively higher. Since the influence from geothermal effect in the Küçük Menderes river basin is very low comparing to the Büyük Menderes and Gedis river basins, it is concluded that the boron including ratio of groundwater in the Küçük Menderes river basin may stay low.

In the area of Küçük Menderes river basin, it is divided into the following three.

1, Selçuk basin
2, Pancar-Torbalı-Bayındır basin
3, Kiraz and Ödemiş-Tire basin

Selçuk Basin may be affected by saline water. Pancar-Torbalı-Bayındır basin is, in general, slightly higher geothermal area and has some relationship between the temperature and the boron including ratio of groundwater relatively. Sporadically the groundwater temperature becomes over 20°C. The boron ratio in the area composed of marble is slightly higher than the other area.

In the Kiraz and Ödemiş-Tire basin, the area composed of gneiss and granite and located between Beydağ and Ödemiş has slightly higher temperature of groundwater. The mountain side of this area shows the relatively better relationship between the temperature and the boron including the ratio of groundwater same as the case of the Pancar-Torıbalı-Bayındır basin. In the Kiraz basin, however, both temperature and boron including ratio are low, and as proceeding to the alluvial area of Beydağ and Ödemiş basin, the temperature become higher; approximately 5°C, being affected by geothermal area, but the boron including the ratio is still low. In the Ödemiş-Bayındır-Tire basin, the temperature becomes low again (boron including ratio is also still low).

2 Water Economy of the Groundwater Basin

(1) General

Due to the lack of hydrological observation data, it was difficult to grasp the hydrological cycle of the basin. It is considered that precipitation is only input to the Basin system and, as for output, some factors such as basin evapotranspiration, stream runoff and groundwater runoff, were not recorded. The water economy of the basin was thus deduced from the known factors, based on common information and experience.

This section describes the water economy among sub-basin blocks in the whole basin. Through the water economy analysis, the quantity of water recharged into the groundwater aquifer was also clarified.

(2) Sub-basin Blocks for Water Economy Analysis

For the convenience of water economy analysis, the basin was divided into 4 sub-blocks based on the topographic and geological conditions, as shown in Figure-C.17.

Sub-block	Character	Area(km^2)
Kiraz Block	Upstream of the proposed Beygağ dam site	515 km^2
Ödemiş-Bayındır-Tire-Torbalı Plain Block	Major ground water aquifer of the Küçük Menderes River Basin	950 km^2
Ödemiş-Bayındır-Tire-Torbalı Mountainous Block	Runoff watershed to the major groundwater basin	1,575 km^2
Tire-Belevi Block	Additional ground water basin	215 km^2
		3,255 km^2

(3) Water Volume Recharged into the Groundwater Basin from the Watershed

The water volume recharged into the groundwater basin from the watershed which consists of mountains and hills, can be estimated from the observed data on precipitation, surface runoff, evapotranspiration(ETo), etc.

The water economy analysis for identification of the recharge was carried out for the Ödemiş-Bayındır-Tire-Torbalı Mountainous block. The analysis covered 20 years from 1974 to 1993, tracing changes in soil moisture by applying the precipitation data of the Ödemiş station and runoff data of the Aktaş river. Apportionment of water obtained through the analysis is as shown in the table below. Detailed results are given in Table-C.3.]

Item	Annual average (mm)	Apportionment (%)
Precipitation	590.0	100.0
Surface runoff	206.0	34.9
Evapotranspiration	312.0	52.9
Recharge*	72.0	12.2

*: Including supplemental water to surface soil layer

(4) Water Volume Recharged into the Groundwater Basin from the Plain Area

The runoff mechanism in the plain area is unknown due to the lack of observations. Therefore, the water balance of the groundwater basin was calculated from the estimated surface runoff. In this Study, the surface runoff was estimated on the basis of a relation curve of effective rainfall, assuming that the surface runoff from the plain area consists of excess water from effective rainfall for farmland.

The water economy analysis for identification of the recharge was carried out for the Ödemiş-Bayındır-Tire-Torbalı Plain Block. The analysis covered 20 years from 1974 to 1993, tracing changes in soil moisture by the applying the precipitation data of the Ödemiş station and the surface runoff values estimated by the above-mentioned method. Apportionment of water obtained through the analysis is shown in the following table below. Detailed results are given in Table-C.4.

Item	Annual average (mm)	Apportionment (%)
Precipitation	590.0	100.0
Surface runoff	127.0	21.5
Evapotranspiration	368.0	62.4
Recharge*	95.0	16.1

*: Including supplemental water to surface soil layer

(5) Water Economy of the Study Basin

The water economy of the whole groundwater basin (3,255 km^2 excluding the Selçuk area) was estimated from the result of estimation of recharge as shown in Figure-C.18. According to the water budget, a volume of 130 MCM has been recharged annually in the Ödemiş-Bayındır-Tire-Torbalı groundwater basin, which is the major groundwater basin in the Study Basin.

Pumping yield has far exceeded water recharge in the major basin, due to not only scarce recharge resulting from recent severe droughts, but also increasing number of pumps within the Study Basin. So far, the water deficit has been covered by retention storage water from the groundwater aquifer. This has caused a drawdown of the groundwater level. Table-C.5 show changes in the water economy according to the pumping yield and recharge during 20 years. According to the water budget, an average annual water deficit of 75 MCM has continued since 1985.

3 Numerical Simulation of Groundwater in the Study Basin

(1) General

A groundwater simulation was carried out in order to confirm the accuracy of the result of the above-mentioned water economy analysis, and to give necessary information regarding effects on the groundwater basin by the development. The Quasi-Three-Dimensional Finite Element Method was applied for the unsteady groundwater simulation analysis. The simulation was performed with around 250 elements modeling the whole groundwater basin, using hydrological data, hydrogeological data, and other data for input and output to the basin.

Feature of the groundwater model is shown in Figure-C.19, and Table-C.6. Simulation term is 13 years since 1980 when is a few years previous to the year in which lowering of groundwater level started. Dimension of each element is 2.5km x 2.5km with own depth based on the actual geological conditions. Hydrogeological parameters, e.g., permeability and effective porosity, were given in each element in consideration of hydrogeological information presented in paragraph previous. The recharge to groundwater basin is inputted in double manners, one is from plain area to charge over the every element and the other is from mountainous watershed through boundary elements which border on the watershed. Pumping yield was given at the total discharge as presented in Table-C.7 and area distribution as the existing pump dispersion in 1980 (refer Figure-C.20, and Table-C.8). Initial groundwater level of each element was adopted a steady level calculated on condition of initial stage of the simulation term.

(2) Identification of the Model

Identification of the Model was done comparing observed groundwater level and simulated one at several DSİ wells which distribute over the Study Basin. Four wells as pointed in Figure-C.21 were selected for the model identification so as to locate impartially in each groundwater basin of Ödemiş-Tire Basin, Bayındır-Torbali Basin and Pancar-Torbali Basin, and to obtain long term precise data of groundwater level. Comparative figures between the observed and simulated data at the selected wells are illustrated in Figure-C.22. These present the results that, the simulated groundwater level seems to be matched well with observed one.

(3) Confirmation of Result of Water Economy Study

Through above identification of the simulation model, all inputs were justified and some parameters were adjusted so as to simulate actual groundwater behavior. Result of simulation on such identified model gives meaningful knowledge regarding water economy of the Study Basin. Grovel water economy presented in previous paragraph can be confirmed by the result of the simulation.

In the grovel water economy, scarce groundwater outflow from the Kiraz basin to the Ödemiş-Tire basin was analyzed. According to the simulation result, such groundwater discharge was a few hundred thousand cubic meter par year, which seemed to be negligibly small in grovel sense. Outflow from the Ödemiş-Tire basin to the Bayındır-Torbalı basin is forecasted to be small due to very narrowed topographic shape. Since the result of the simulation indicated small quantity of outflow of several hundred thousand cubic meter per year passes through the neck point, both sub-groundwater basins could be regarded as an independent basin each.

The simulated groundwater flow vector at each element in winter and summer seasons presented in Figure-C.23. It shows general direction of flow and discharge at any locations, and it explains the fact that a remarkable flow is found in the central portion of the Ödemiş-Tire basin only.

(4) Testing of Adequacy of the Pumping Yield Limit

As mentioned in subsequent paragraph, it is recommended to execute control of pumping yield restricting at 160 MCM par year. A simulation study on pumping yield limit was carried out in order to examine the adequacy of such control of pumping. The simulation was done under the condition of pumping yield which was given smaller than or equal of 160 MCM. The simulated groundwater level for controlled pumping yield at 4 existing wells of which data of groundwater level were utilized for model identification, are shown in Figure-C.22. According to the result of simulated groundwater level, those did not cause remarkable lowering of groundwater level, though there was little drawdown. Consequently, the limit volume of groundwater yield can be concluded as reasonable.

However, the result of simulation shows the necessity of consideration for spatial distribution for the pumping yield control. While no phenomenal groundwater lowering is found in each central portion of the Ödemiş-Tire basin and the Bayındır -Torbalı basin in case of applying parentage of pumping control at 64% (controlled from 250 MCM to 160 MCM in total), a severe control is required in marginal area of the basins. On the contrary, generous control may be permitted in the Pancar-Torbali basin due to sufficient groundwater.

(5) Effects of Dam Construction to the Groundwater Basin

As the groundwater basin is continuously recharged from mountainous watershed which is located northern and southern part of the Study Basin, it was worried that construction of proposed dams would interrupt such recharging from concerned tributaries to the groundwater basin. The groundwater simulation also gives obvious answer for this question.

A groundwater simulation was carried out on the assumption that recharge from tributaries concerned decreased to a half of the same in the present situation. Different heights of groundwater level between with and without construction of 4 proposed dams excluding the Uladi dam at each model's element are illustrated in Figure-C.24. According to this result, the maximum different height of around 4m was found at just downstream of each concerned dam site excluding Beygağ dam site. However, no bad influence in groundwater use will be recognized, because the irrigation water source of such area where the lowering of groundwater level is expected through the dam construction will be shifted from the present groundwater use to surface water supply from the proposed dam reservoirs. In the central area of the basin, 1.0~2.0 m lowing of groundwater level may occur. This much lowering can be regarded as no harm.

In this analysis, the increment of recharge by leakage from the dam reservoir was not considered. As such increment of recharge into the downstream area may occur, the effect of dam construction is expected smaller than the simulated results presented in Figure-C.24.

4 Maximum Groundwater Yield for Sustainable Use

It is estimated that groundwater has recently been pumped up from the major basin at a rate of around 250 MCM/year, far exceeding the annual water recharge volume. If such over-pumping continues, either groundwater will be exhausted soon, or pumping will be compelled to stop due to rising O&M expenditures for deeper pumping. Therefore, urgent execution of quantitative control of pumping is required.

It is assumed that the recent rapid lowering of the groundwater level in the basin was caused not only by over pumping, but also by a series of drastic droughts since 1985. There was an argument on wether such droughts with a very low probability should be considered or not in determining the pumping yield if such severe droughts are taken into account.
In this Study, the maximum pumping yield of 160 MCM/year was applied for the reason that the series of droughts occurred since 1985, which had an approximate 1000-year return period, was an extreme event beyond consideration, and that setting up a target which is far away from the present condition is not realistic and not feasible.

5 Alternative Study for Groundwater Recharging

(1) General Description:

Groundwater use in the Küçük Menderes river basin is not sustainable due to over pumping which is imbalance with recharging into groundwater. The final development plan of this Project has been established by means of surface water development through the construction of 4 dams because of higher economy in this case. During the Study, groundwater recharging plan was also studied as an alternative, but this plan was not adopted as an optimum scheme in the Project, though it may be feasible in future, if some circumstances change. The groundwater recharging plan devised in the Study is described here under as a reference.

(2) Methods for Groundwater Recharging in General

Methods for groundwater recharging are generally divided into two groups of Direct Method and Indirect Method. For the emergency case, or for wider area, direct method is recommended rather than the indirect method. Techniques of the direct method are enumerated below.

1) Recharge by surface application or spreading
    - Basin method
    - Ditch or furrow method
    - Flood or sheet-flood method
    - Pit method
2) Recharge through well
3) Recharge by combination type
4) Recharge by sub-surface dam

(3) Suitable Recharging Method:

The groundwater basin of the Küçük Menderes river is broadly divided into 2 groundwater basins of Ödemiş-Tire and Bayındır-Torbalı. Both groundwater basins offer advantageous groundwater storage having narrowed end.

In Ödemiş-Tire basin having area of 51,000 ha, present annual pumping yield is 140 MCM which is far exceeding the annual amount of groundwater recharging of 74 MCM. Groundwater of around 10 MCM escapes from this basin to below Bayındır-Torbalı Basin through the bottle neck. Furthermore, the quantity of water more than three times of recharged amount leaves downstream as the surface flow of the Küçük Menderes river. Taking these conditions into consideration, the lower availability of groundwater in the groundwater basin is caused by the limited rechargibility, not escaping much groundwater from the neck. By this reason, it is concluded that effort to increase recharge from ground surface is far effective rather than to check escaping water from the neck. Accordingly, a method for recharging of groundwater will be recommended rather than the construction of sub-surface dam at the bottle neck.

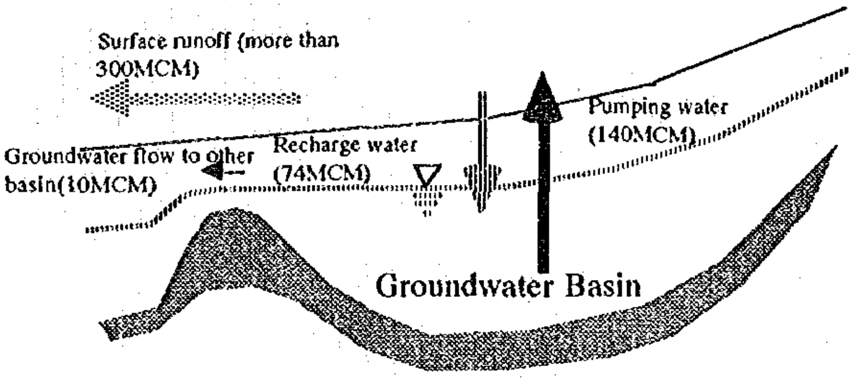

Illustration of Odemiş-Tire Groundwater Basin

In Bayındır-Torbalı basin having area of 39,000 ha, annual pumping yield is 110 MCM which is also far exceeding the annual amount of groundwater recharging of 56 MCM. Underground flow of around 99 MCM runs from this basin to the downstream area of Selçuk through the bottle neck in the downstream side. Since this underground flow is not groundwater but sub-surface flow of the Küçük Menderes river swamping the downstream portion of the groundwater basin, it can not be used as the water sources. Drainage measures against such swamping have been taken, and the underground water is more or less removed through the constructed drainage canals. Though it is possible to stop some of the underground water by means of construction of sub-surface dam at the bottle neck, severe swamping around downstream area of the basin must recur, if such a sub-surface dam is constructed. By this reason, it is also concluded that the effort to increase recharge from ground surface is far effective rather than to decrease escaping water from the bottle neck. Accordingly, a method for recharging groundwater will be recommended rather than construction of sub-surface dam at the bottle neck.

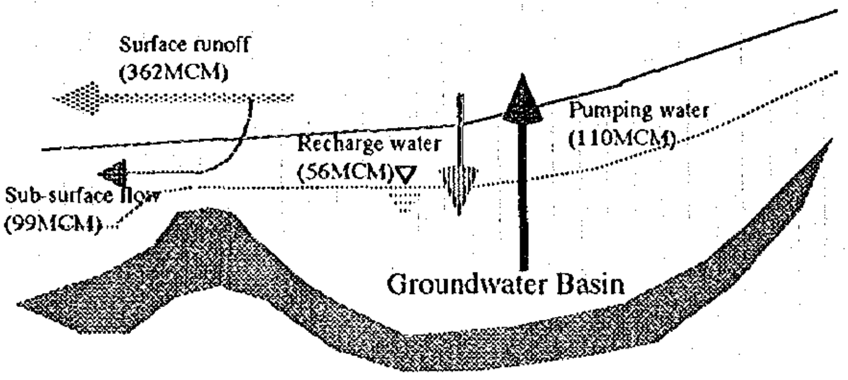

Illustration of Bayındır-Torbalı Groundwater Basin

(4) Proposed Countermeasure for Recharge in the Project

It is concluded in the above that a method for recharging groundwater from ground surface should be applied to the basin as an effective countermeasure for the recharging in the Project Area. Among the ordinary recharging methods mentioned above, the recharge by surface application or spreading in the direct method should be selected from the viewpoint of economy and technical applicability.

According to the meteorological condition and flow regime in and around the Study area, water to be used for the use of recharging groundwater is flood broken out in short term during the rainy season. Therefore, a method to catch and store effectively such floods should be studied for the recharging. As the one of methods, a construction of many ponds for recharging from the bed is conceivable, but this method is not recommended due to high cost and difficulties for water use.

Considering the situations mentioned above, the combined method for the basin method and flood method is devised for this project. Under this combined method, the proposed tertiary drains will be designed to have a wider sections than the required for the drainage purpose, so that the flood water stays in the drains for a longer time, which would result in more recharging effect. The schematic diagram of this method is as shown below.

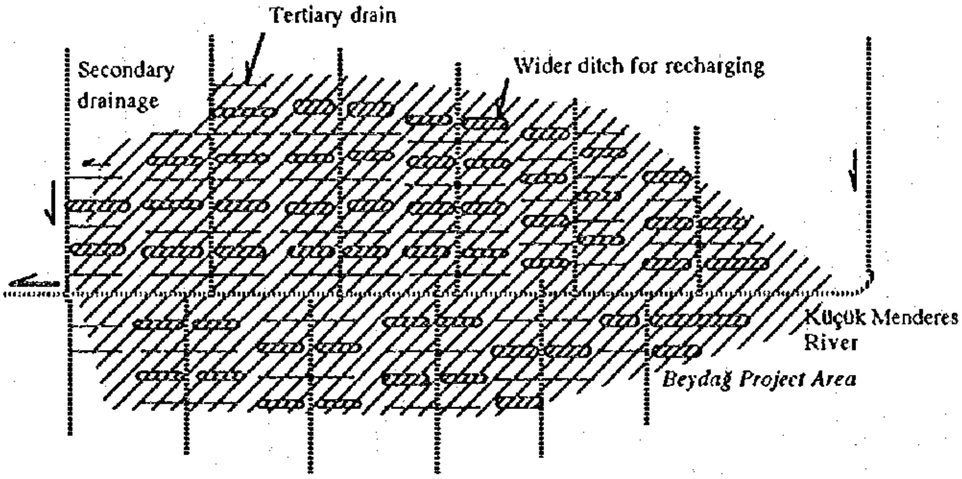

Illustration of Proposed Wider Ditch for Groundwater Recharging

This plan could be regarded as the optimum recharging method in the river basin. However, this method was not adopted for the Project, because it is inferior to the surface water development plan which was adopted under the Project. After realizing the Project following the surface water development plan, the above-mentioned recharging method can be taken up in succession, when the water supply situation in the river basin is required so.