THE REPUBLIC OF TURKEY
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FEASIBILITY STUDY
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ANNEX-A Geology
ANNEX-B Construction Materials

DECEMBER [illegible]

JAPAN INTERNATIONAL COOPERATION AGENCY
TOKYO, JAPAN

THE REPUBLIC OF TURKEY
ELEKTRİK İŞLERİ ETÜD İDARESİ
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FEASIBILITY STUDY ON ERMENEK HYDROELECTRIC POWER DEVELOPMENT PROJECT

VOLUME 3

SUPPORTING REPORT 1

ANNEX-A Geology
ANNEX-B Construction Materials

DECEMBER 1990

JAPAN INTERNATIONAL COOPERATION AGENCY
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ANNEX-A GEOLOGY

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CHAPTER 1. INTRODUCTION

This report describes the geological investigation results for the Feasibility Study of the Ermenek Hydroelectric Power Development Project. The investigations were carried out by EİE for the project definition from 1984 (pre-F/S study). And then, the additional geological investigations were performed jointly by JICA and EİE from 1989 to 1990 for the feasibility study of the Project. All the investigation results are compiled in this report.

The following geological investigations were carried out by EİE from 1985, before the feasibility study.

Geological mapping of the reservoir area
(1/25,000 scale)
Geological mapping of the project area
(1/5,000 scale)
Core boring investigation and Lugeon test
Geophysical survey
Test adit excavation in I-B damsite
Micropaleontological and mineralogical study

The study results of the above investigations are described in the following reports by EİE.

(1) INTERIM GEOTECHNICAL REPORT FOR ERMENEK DAMSITE
Yayin: 88-7, September 1987

(2) ERMENEK BARAJ YERİ JEOFİZİK RAPORU
Yayin 87-43, April 1987

(3) ERMENEK HES PROJESİ KUVVET TÜNELİ GÜZERGAHI JEOFİZİK ETÜT RAPORU
Yayin: 88-24, May 1988

In the Feasibility Study (F/S study) from 1989 to 1990, the following additional geological investigations and review of the above-mentioned investigation results were performed.

- Geological mapping of I-C damsite area (1/1,000 scale)
- Geological mapping of Erik intake area (1/500 scale)
- Core boring investigation
- Seismic exploration
- Test pit excavation
- Test adit excavation in I-C damsite
- Laboratory test
- Study of seismicity
- Mineralogical study

CHAPTER 2. GEOLOGICAL INVESTIGATION

2.1 Geological Mapping

The following geological maps were prepared for the F/S study.

Plate G1	Geological map of reservoir area	: 1/25,000
Plate G2	Geological map of project area	: 1/5,000
Plate G3	Geological map of damsite I-C	: 1/1,000
Plate G22	Geological map of Erik intake site	: 1/500

The geological map of reservoir area (Plate G1 of Volume 5: Drawings) and the geological map of Project area (Plate G2) were prepared in pre-F/S stage. These were partly revised based on the results of the field reconnaissance survey in F/S stage.

2.2 Boring Investigation

The core boring investigation of 7,438.75 meters in total (5,111.05 meters in pre-F/S stage and 2,327.70 meters in F/S stage) were performed for the proposed damsite I-B and I-C, power house area, headrace tunnel route, landslide area, tailrace outlet and limestone area near the Nadire spring (backwater area) as shown in the attached Table A2. The borehole location is shown in Plate G2. Lugeon tests, 1,191 times in total (968 times in the pre-F/S stage and 223 times in the F/S stage) were performed in these boreholes.

The results are summarized in the geological profiles for each structure site, Fig. A7 and listed in the Drill Log in the Attachment A1 hereto.

2.3 Geophysical Investigation

In the pre-F/S stage, the following investigations have been performed.

Damsite I-B area (1987):

Vertical electric sounding
(resistivity method): 84 points

Seismic exploration
(refraction method) : along 17 profiles

Damsite I-C and headrace tunnel route areas(1988):

Vertical electric sounding
(resistivity method): 109 points

Seismic exploration
(refraction method) : along 14 profiles

In the F/S stage, seismic exploration (refraction method) of 9 lines (9,360 meters) in total was performed as shown in Table A3. The results of the F/S stage are shown in the geological profiles for each seismic line; Plates G8, G9, G10, G11, G16, G17, G19, G20 and G21, and Attachment A3. The locations of these points and lines are shown in Plate G2.

2.4 Test Adit Investigation

The excavated test adits are as follows:

I-B damsite: 42 meters in length, in the right bank.
(pre-F/S stage)

I-C damsite: 231.2 meters in length, in the right bank.
(Access tunnel of 186.40 meters and
test adit of 44.80 meters, F/S stage)

The geological sketch is shown in Fig. A9.

2.5 Laboratory Test

The test samples were taken from the boring cores of SK-302, 307 and 313. The test items and quantities are summarized as follows.

Test item	Test quantity (samples)
Specific gravity & water absorption	18
Unconfined compression test	18
Super sonic wave test	18

The results are summarized in Table A4.

2.6 Study of Seismicity

The study report; ERMENEK BARAJ VE HES YERİ DEPREMSELLİK RAPORU (Yayin: 90-3, January, 1990) prepared by EİE, was partly revised by the JICA Study Team. The study results are explained in Chapter 6, and the earthquake record is listed in the Attachment A5.

2.7 Micropaleontological and Mineralogical Study

The micropaleontological and mineralogical study was performed in the pre-F/S stage for 53 samples taken in the field in order to confirm the geological age of each limestone block in the study area. The sampling location is shown in Plate G26.

In F/S stage, mineralogical study was performed for 4 samples taken from SK-102 and outcrops in the power house area in order to examine swelling tendency of rocks by X-ray diffraction method and microscope. The results are summarized in Table A10, and the details are listed in Attachment A4 together with the results of pre-F/S study.

CHAPTER 3. REGIONAL GEOLOGY

3.1 Previous Geological Investigation

The following geological investigations were carried out for the Ermenek river basin before the JICA feasibility study.

(1) Geological preliminary report on Göksu-Ermenek damsite, Possibilities and their reservoir areas. EİE, 1975-1977.

(2) Gülnar Ilisu (Erik river) hydroelectric project, Engineering geology study. EİE, 1975.

(3) The geology and oil possibilities of Mut-Ermenek-Silifke Region. Bulletin of Turkish Geological Society (No.22, pg.7-26). Gedik A. et.al. (Investigation period; 1975-1976.)

(4) Stratigraphic and tectonic study for the Göktepe area in the western part of the study area. Blumenthal (1956), Özgül (1976), Demirtaşli, et.al. (1978), and Kuşçu (1985).

All the description in this chapter is based on the Interim Geotechnical Report for Ermenek Damsite, EİE, 1987, while some parts are revised by the investigation results of the JICA F/S study.

3.2 Topography

The Ermenek river is the biggest tributary of the Göksu river, and joins the Göksu river in the vicinity of Mut city. The Göksu river basin is located in the middle part of the Central Taurus Mountain Range (Central Taurides) which is developed along the Mediterranean coast. The Central Taurus Mountain Range is a geographical subdivision of the Taurus Belt in the south-eastern Anatolia.

The Taurus Belt is divided into three ranges, i.e. Western, Central and Eastern Taurus Mountain Ranges. These ranges are defined as the areas by two major tectonic structures. In the west of Alanya city, NW-SE trend structure is the border between Western and Central Taurus Mountain Ranges, and in the east near Adana city, NE-SW structure (Ecemiş fault) is the border between Central and Eastern Taurus Ranges (Refer to Fig. A1).

The study area, which is located in the midstream of the Ermenek river, covers the whole areas of proposed dam and reservoir, damsite, headrace tunnel route, powerhouse area and Erik intake site. The proposed damsites are located in the south of the Ermenek city, near the Görmel bridge. The power house area is located at about 10 kilometers downstream from the damsite, and the reservoir will extend up to about 20 kilometers upstream from the damsite, near the Nadire spring. The Erik intake site is located at 4 kilometers upstream form the confluence of the Ermenek river.

The Topography in the surrounding area of the Ermenek river show rather flat plateau with 1,500 - 2,200 meters in elevation, which is formed by mainly thick and horizontally bedded limestone layers of Tertiary Miocene Ermenek formation.

In the study area, the Ermenek river flows from west to east. The main tributaries in the study area are Küçük river and Balkusan river in the northern area of the Ermenek river, and Zeyve river and Erik river flowing from south to north in the southern area of the Ermenek river basin.

In the area between Küçük river and the Zeyve river which is the major part of the dam reservoir, both banks are formed by rather gentle slopes, where the foundation rock is mainly marl of Tertiary Görmel formation. In this area, some remnants of historical landslide are seen on the slopes of both banks, especially on the left bank. Now these are in stable condition, and any sliding activity can not be seen in the area.

In the upstream area of the Küçük river and downstream of the Zeyve river, both banks are formed by steep mountainous slopes, where the rocks are mainly composed of Cretaceous Ermenek Ophiolitic Melange. Where the river flows in limestone blocks, the both banks show very narrow and deep gorges.

Most of the flows of the Ermenek river originate from Kapiz spring and Nadire spring located in the west part of the study area, while the uppermost reaches of the river are located on the limestone plateau. The flows of the above-mentioned tributaries also originate from springs, such as Balkusan spring, Zeyve spring, Erik spring, etc. The river flows in the upstream reaches of these springs are generally very little or almost nil, especially in the dry season. These springs are seen in the limestone blocks of the Ermenek Ophiolitic Melange, and in the foot slopes of steep cliffs of Miocene limestones which are distributed on the top part of both banks forming the plateau.

3.3 Geology

In the study area, the Upper Cretaceous Ermenek Ophiolitic Melange outcrops in the vast areas as a basement. It is composed of Carboniferous-Upper Cretaceous blocks of sedimentary rocks, mainly limestone, in different character, and the matrix layers. The Çimene group of Carboniferous-Triassic age which is the oldest stratum in the study area was identified in the study of pre-F/S stage. The Çimene group was not known either the basement formations of the project area, or an olistolith (block) in the Ermenek Ophiolitic Melange to date. However, it is considered as olistolith in this report.

In the west area, the Aladağ unit of Palaeozoic-Mesozoic age (Özugül, 1976) thrusted over the Ermenek Melange probably at Palaeogene in Tertiary age. There is a tectonic contact (thrust fault) between the Aladağ unit and Ermenek Ophiolitic Melange. In the study area, two numbers of formations of Aladağ unit, namely Balcilar formation of Upper Triassic age and Cihandere formation of Jurassic-Lower Cretaceous age are seen.

The Cenozoic Tertiary formations, namely Görmel formation of Lower Miocene age and Ermenek formation of Middle Miocene age are representative in the study area. The Quaternary deposits, such as terrace deposit, talus deposit, etc. are seen widely on the slopes and along the rivers.

The most recent and main tectonic deformation was developed during the period of Palaeogene to Miocene in Tertiary age. After that, the area was uplifted by the effect of epeirogenesis and then the various erosion occurred during late Tertiary and early Quaternary age, and the present topography of the region was formed.

The geological map in the reservoir area is shown in Plate G1; geological map of the project area in Plate G2; and the geological formations distributed in the reservoir area is summarized in Table A1. Each geological formations are as follows.

3.3.1 Aladağ unit

Paleozoic-Mesozoic age deposits outcropping in the western part of the study area consist of platform type carbonate rocks. These were called as Black Aladağ unit by Blument Hal (1952) in the Aladağ region. The Aladağ unit consists of Göksu, Dumlugöze, Haydar, Balcilar and Cihandere formations from old to young.

While the Aladağ unit is not easily recognized everywhere due to the thrusting, two formations, Balcilar formation of Upper Triassic age and Cihandere formation of Jurassic-Lower Cretaceous, are seen in the western part of the study area. Cihandere formation which is conformable with Balcilar formation, and overlies the Ermenek Ophiolitic Melange with the tectonic contact (thrust fault) at the west and south of Nadire spring. Each formation is as described below.

(1) Balcilar formation (ÜTrb)

The Balcilar formation outcrops in the west end part of the study area. The lowest part of this formation is formed by reddish colored conglomerate of the lower part of this formation. The upper section is made up of clayey limestone and red - claret red colored shale layer which is interbedded with sandstone. The uppermost layer is thin bedded dolomitic limestone.

This formation lies on Haydar formation unconformably. On the other hand, this is overlain by Cihandere formation conformably.

(2) Cihandere formation (JKc)

The Cihandere formation outcropping between Balcilar formation area and the above-mentioned tectonic contact, consists of dolomitic limestone, oolitic-pisolitic limestone and light gray colored limestone layers from the bottom to the top. The lower sections of this formation show neritic sea condition, and the upper sections show abyssal sea condition.

This formation lies on Balcilar formation conformably. Its contact with Ermenek Ophiolitic Melange is tectonic (thrust fault).

3.3.2 Ermenek Ophiolitic Melange

In the study area, the Ermenek Ophiolitic Melange forming the basement for the Görmel and Ermenek formations outcrops in large area between Küçük river and Yesilkoy, and in the eastern part of the proposed damsite along the Ermenek river. The Ermenek Ophiolitic Melange consists of heterogen blocks of sedimentary rocks of Carboniferous-Upper Cretaceous age and matrix layers. The size of blocks shows occasionally more than one kilometer. The oldest blocks are estimated to be Çimene group of Carboniferous-Triassic age, and the youngest blocks are estimated to be Upper Cretaceous. Then it is considered that the age of this melange corresponds to late Upper Cretaceous.

Micropaleontological and mineralogical study was carried out in order to recognize the geological age of each block in the melange. The sampling location for the study is shown in Plate G26, and the study results are summarized in Table A7 and in Attachment A4 in detail.

(1) Blocks

(A) Çimene group

The Çimene group outcrops along the Ermenek river in the east part of the study area, between the proposed damsite and power house site. This group is divided into three formations from bottom to top: Balkusan, Eskice and Tahtaci formations.

(a) Balkusan formation (Kçb)
The lowest part of the Balkusan formation of Carboniferous age, which corresponds to the lowest part of the Çimene group is not seen in the study area. This formation is composed of moderately to thickly bedded, blackish-dark gray colored and hard limestone which has lapies on its surface. The Balkusan formation is overlain by Eskice formation conformably.

(b) Eskice formation
The Eskice formation of Permian age lies over the Balkusan formation conformably. Because of its lithologic properties, it is divided into three members from bottom to top; Pürelicenin, Akarca and Saribayir members. Some transitions between Saribayir and Akarca members are observed in the study area. The Eskice formation is conformable with Balkusan and Tahtaci formations.

Pürelicenin member (Pçep):
The Pürelicenin member which corresponds to the lowest layers of the Eskice formation consists of red, brown, yellow and claret red colored limestone. This limestone shows brittle, thinly and moderately bedded, and partly sandy. This member is non-fossiliferous, but was accepted as Lower Permian according to the stratigraphical sequence.

Akarca member (Pçea):
The Akarca member consists of thinly to moderately bedded, dark gray and black colored fossiliferous limestone, with calcite veins. It shows great resemblance to the Gökçeseki formation of Permian age. The limestone shows moderately hard, with solution traces and lapies.

Saribayir member (Pçes):
The Saribayir member consists of moderately bedded, grayish and brownish colored limestone, with thin to moderately bedded, pinkish to brownish quartzite and grayish to greenish shale layers. No fossils were found in this member, but this has lateral and vertical transitions with black colored limestone of Akarca member.

(c) Tahtaci formation
The Tahtaci formation of Triassic age consists of light gray, brownish and beige colored limestone, which is divided into two members; Ardiçli and Tasdibi members from lower to upper as follows.

Ardiçli member (Trçta):
The Ardiçli member consists of massive, moderately to thickly bedded and hard limestone in general.

Taşdibi member (Trçtt):
The Taşdibi member consists of thinly bedded, moderately hard and brittle limestone. This is not easily recognized in the study area due to thick talus deposit cover. There are some lateral and vertical transitions

between theTaşdibi and Ardiçli members.

(B) Nisa formation (Pn)

The Nisa formation of Permian age appearing in the area near the confluence of Balkusan river consists generally of massive, brown to beige colored limestone. This block looks like a floating unit in the matrix layers which are formed by graywacke and ophiolitic rocks.

(C) Gökçeseki formation (Pg)

The Gökçeseki formation of Permian age is found in ophiolitic rocks southwest of Çamlica village, and in the right bank of Ermenek river about 3 kilometers downstream from the proposed damsite, surrounded by sandstone of matrix layers. This formation consists of black colored, thinly to moderately bedded and hard limestone, with quite numerous calcite veins. It has some solution traces and lapies, and shows great resemblance to the Akarca member of Çimene group.

(D) Kükürce formation (Trk)

The Kükürce formation of Upper Triassic age is composed of brown, beige to gray colored, thinly to moderately and occasionally thickly bedded, rarely jointed and hard limestone. It has solution traces and lapies on its surface.

A huge limestone block of this formation is located at about 3 kilometers west from the proposed power house site, and small limestone blocks are found in the north area of the huge block. The huge limestone block is surrounded by matrix layers which contain mainly graywackes, and diabases in the north, south and west part of the blocks, and gabbro and serpentinized peridotite in the east part.

In the northwestern part of the huge block, there may be a fault between the block and graywacke. Besides, an old fault with a strike of N42°E is estimated to be in the block. The small blocks seems to be floating units in graywacke.

In a block which is located in the left bank of Ermenek river at about 3 kilometers downstream of the proposed damsite and surrounded by graywackes, no fossils, suitable for age determination have been encountered. However, the limestone forming this block shows lithologic similarities to the Kükürce formation. Therefore it is described that this block belongs to the Kükürce formation in this study.

(E) Azitepe formation (Ja)

The Azitepe formation of Jurassic age outcrops in the area between Çamlica village and Ermenek river, surrounded by ophiolitic rocks in general. It is generally white, cream, beige to pinkish colored, thinly and moderately bedded, densely jointed and hard limestone, with some solution traces and lapies on its surface.

(F) Nadire formation (Jkn)

In the study area, all the limestones which could not be determined clearly, provably Jurassic-Upper Cretaceous, were named as Nadire formation in this study.

The Nadire formation outcrops widely in the study area. The proposed damsite I-C and power house also are located in this formation. The biggest block is seen in the upper reaches between Nadire spring and Küçük river, which also have no characteristic fossils for age determination according to the previous study (by MTA; Mineral Research and Exploration Institute, Ankara, from 1983).

In the study area, all the blocks of Nadire formation are generally surrounded by ophiolitic rocks, which are generally formed by white, cream, beige to gray colored, very hard, thinly to moderately bedded, occasionally massive in appearance and karstic limestone.

In the area between Küçük river and Nadire spring, the Nadire formation is formed by dolomitic limestone which is dark gray to black at weathered surfaces, and brown, beige to gray at fresh surfaces, sugar textured and hard rock, with solution traces and lapies. Besides, the Nadire formation includes some claystone and marl layers in the upper layers in this area.

(2) Matrix layers

The matrix layers of Ermenek Ophiolitic Melange are composed of several kinds of sedimentary rocks and ophiolitic rocks. In the study area, the matrix layers are formed by diabase, serpentinized peridotite, gabbro, graywacke, graywackish sandstone, schist, conglomerate, etc.

The graywackes are typically seen together with the ophiolitic rocks in the area near the huge block of Kükürce formation and in the east and west area of

Ağaççali village at about 2 kilometers north from the proposed damsite. It is dirty yellow colored, well stratified and moderately brittle rock, and contains some fragments of quartz, limestone and ophiolite. Bedding thickness varies between 5 and 10 centimeters.

Serpentinized peridotite, gabbro, diabase and schist frequently occur in the area where the Ophiolitic Melange outcrops. These rocks show dark green, blue, brown and black colors. Therefore the ophiolitic rocks are easily recognized in the field. These ophiolitic rocks are in general moderately hard and friable.

3.3.3 Görmel Formation (Tg)

In the study area, the Görmel formation covers vast areas on both banks of the Ermenek river.

Since the Görmel formation is filling up the eroded area of the Ermenek Ophiolitic Melange, its thickness is much variable. The apparent thickness is about 700 meters in the southwest area of Üçbölük village, which is located at about 3 kilometers southeast from the proposed damsite.

The Görmel formation might be deposited in flyish facies, which is composed of mainly marl, and partly claystone, sandstone, clayey limestone and conglomerate. Marl is green (weathered surface) and greenish to dark gray (fresh surface) colored, rather well bedded in general, brittle and soft rocks.

Claystone is green to greenish gray colored, well bedded, brittle and soft rock. Sandstone is dark greenish gray and brown colored, rather well bedded and moderately hard rock. Grains of sandstone are serpentinite, limestone, quartz, biotite, etc. Clayey limestone is gray to beige colored, well bedded, brittle and moderately hard rock.

Conglomerate is yellowish white to light gray colored, moderately hard to hard rock, which is formed mainly by limestone, serpentinite and quartzite gravel, generally loosely and occasionally densely cemented by sandy to clayey materials. Gravel is rounded or subrounded, 2 to 4 centimeters in diameter in general.

Some coal bands exist in the Görmel formation. A coal mine which is currently being in operation is located on the right bank of Küçük river in the southwest of Ermenek city.

The Görmel formation is in angular unconformity with the lower formation of the Ermenek Ophiolitic Melange, and also this is overlain by the Ermenek formation with angular unconformity.

No fossils were found in the samples which were collected in this study. During the previous studies (by MTA), the age of this formation has been considered as Tertiary Lower Miocene.

3.3.4 Ermenek Formation (Te)

The Ermenek formation outcrops at rather high elevations, in the northern and southern parts of the study area with steep cliffs along the Ermenek valley. Because of its karstic appearance, the Ermenek formation is recognized easily in the field. The thickness of this formation is estimated to be about 500 meters in the upstream reaches of Küçük river.

The Ermenek formation is composed of mainly limestone, partly sandy limestone, sandstone and marl, which shows horizontal and vertical transitions. Limestone is gray to beige (weathered surface) and cream to white (fresh surface) colored, rather well bedded, chalky and moderately hard rock. It is karstic and its surface shows many solution features and lapies. Sandy limestone is white colored, rather thick bedded, chalky and moderately hard rock. Sandstone is right brown colored, rather well bedded and moderately hard rock, formed by mainly serpentinite and limestone grains. Marl is light gray colored, well bedded, brittle and soft rocks.

It is quite difficult to distinguish the contact between Ermenek formation and Görmel formation, because weathering is extensive in the surface zones of both formations and thick talus deposits cover the contact.

The Ermenek formation overlies Aladağ group, Ermenek Ophiolitic Melange and Görmel formation with angular unconformities. During the previous studies (by MTA), the age of this formation has been considered as Tertiary Middle Miocene.

3.3.5 Quaternary deposit

(1) Diluvial deposit (Qtr)

The diluvial terrace deposits (Qtrt) are distributed rather widely on both banks of the Ermenek river in the area from Küçük river to the proposed damsites overlying the Görmel formation, and are generally weekly carbonate cemented. These deposits consist of rounded gravels, boulders, occasionally blocks and sandy to clayey materials, which are generally limestone and rarely ophiolitic rocks.

(2) Alluvial deposit (Qar)

The alluvial riverbed deposits (Qalr) and terrace deposits (Qtrt) are widely developed in the area between Küçük river and the proposed damsites along the Ermenek river. The deposits are generally composed of sand and medium to coarse gravels. In the upstream area from Küçük river and the downstream area from the proposed damsites, these deposits are seen only in narrow areas along the river but have very big boulders.

Talus deposits (Qalt) are well developed on the slopes of both banks of Ermenek river. On the left bank of Ermenek river in the upstream area of the proposed damsites, debris of old landslide is developed widely.

3.4 Geological Structure

(1) Fold structure

In the study area the folds are seen in the blocks of Ermenek Ophiolitic Melange and Görmel formation. However these folds are mostly small and local, especially in the Görmel formation. The only one which can be recognized in the field is an EW trending anticline in the blocks of the Çimene group in the Melange along the Ermenek river in about 3 kilometers south of Eskice Village.

(2) Fault structure

Several numbers of faults, such as F1, F2 and F3 in the proposed damsite I-C, are seen in the Nadire, Azitepe and Kükürce limestone blocks of the Melange. However, these are mostly minor faults geologically. In the Görmel and Ermenek formations in the study area, any big fault structures could not be recognized.

Thrust fault is seen in the western part of the study area near Nadire spring where the Aladağ unit overthrusts the Ermenek Ophiolitic Melange. The age of this thrusting is estimated to be Palaeogene of Tertiary age. The dip of this thrust could not be measured in the study area.

3.5 Springs and Groundwater Level in the Project Area

3.5.1 Major springs

Many springs are seen in the reservoir area from the lower to higher elevations, and the sources of the Ermenek river and its main tributaries are mostly these springs as described in Section 3.2. The major springs in the reservoir area are Kapiz spring, Nadire spring, Ermenek spring, Zeyve spring and Erik spring as described below.

(1) Source of the Ermenek river

Two main springs, Kapiz and Nadire springs are the source of the Ermenek river as follows.

Kapiz spring:
The Kapiz spring is located on the right bank of the river at an elevation of about 680 meters, about 2 kilometer upstream from the Nadire spring, which is the biggest source of the Ermenek river. The spring discharge quantity is estimated to be 2 to 3 m^3/sec in dry season and to become 1.5 to 2 times in rain season. The spring is seen scatteringly in the talus deposit formed by mainly limestone boulders. Below these talus deposits, it is estimated that a thrust fault is running across the river.

The downstream area of the fault is composed of the ophiolitic rocks of the Ermenek Ophiolitic Melange, and the upstream of the fault is formed by the limestone of the Cihandere formation of Aladağ group. The limestone of the Cihandere formation is widely distributed in the upstream area of the spring, and is widely covered by the highly karstic limestone of the Ermenek formation.

Consequently, the source of spring is estimated to be groundwater in the limestone of the Cihandere formation. The recharge area of this groundwater may be the limestone of the Ermenek formation.

Nadire spring:
The Nadire spring is located on the right bank at an elevation of about 700 meters, about 10 kilometers upstream of the confluence of the Küçük river. The spring is gushing out directly from cavities in the limestone block of the Nadire formation in the Melange. The spring discharge quantity is estimated to be 1.5 to 2 m^3/sec in all seasons.

The limestone block is estimated to be overthrusted by the limestone of the Cihandere formation in the higher part of the slope in this area, and the Cihandere formation in the top part of the slope is covered widely by the limestone of the Ermenek formation. Therefore, the recharge area of this spring is also estimated to be the Ermenek formation.

(2) Ermenek spring

The Ermenek spring is located at an elevation of 1,100-1,200 meters, just behind the Ermenek city and this spring is being used as the main water supply source to the city. The spring quantity is estimated to be several cubic meters, may be 2 to 3 m^3/sec. The spring water directly comes out from big cavity in the limestone of the Ermenek formation. The recharge area is the Ermenek formation which is widely distributed in the northern area of the city.

(3) Zeyve spring

The Zeyve spring is the main source of the Zeyve river, located at an elevation of 750-800 meters, near the Zeyve village on the right bank slope of the Ermenek river. The spring quantity is estimated to be 1 to 2 m^3/sec. The slope is covered by thick talus deposit. Rocks below the talus deposit are estimated to be the Görmel formation (mainly marl). The southern plateau area of the spring, the Ermenek formation, is widely distributed and may be the recharge area of the spring.

(4) Erik spring

The Erik spring is located at an elevation of about 817 meters, in the right bank of the Erik river at about 4 kilometers from the confluence of the Ermenek river, and is the main source of the Erik river. The spring quantity is estimated to be 1 to 2 m^3/sec.

The spring water is gushing out directly form a cavity in the limestone block of the Kükürce formation in the Melange. This limestone block is estimated to be continued toward east, and the top portion of this block may directly be covered by the limestone of the Ermenek formation which is distributed widely in the upstream plateau area of the Erik river basin. The recharge area of the spring may be the plateau area formed by the Ermenek formation.

3.5.2 Groundwater level

Many springs are seen at various elevations, almost from the Ermenek riverbed (EL.700 m) to the Ermenek city (EL.1,100 - 1,200 m). And the recharge areas for these springs are estimated to be all the plateau formed by highly karstic limestone of the Ermenek formation, which is distributed widely at elevations of 1,500 to 2,200 meters, in the southern and northern areas of the Ermenek river basin. Therefore, it is considered that the groundwater levels in both banks of the Ermenek river may be rising from the riverbed towards the plateaus in general.

The reservoir area is formed by the Ermenek Ophiolitic Melange and Görmel formation, which are all low pervious rocks in general, except the limestone blocks in the Melange. The limestone blocks are scattered in the reservoir area, and some blocks are estimated to be directly connected to the limestone of the Ermenek formation. Such blocks show sometimes very high potential of groundwater and have big springs, as mentioned in Sub-section 3.5.1. Other blocks, such as the block in which I-C damsite is located, show rather low groundwater levels, almost similar to or slightly lower than the Ermenek river water level. However, these low water levels seems to be very local and limited only in these limestone blocks, being independent from others. In the surrounding areas of these blocks which are formed by ophiolite and other sedimentary rocks, the water levels show much higher than those in the limestone blocks in general.

CHAPTER 4. ROCK PROPERTIES IN THE PROJECT AREA

4.1 Seismic Velocity

According to the results of seismic exploration, the estimated seismic velocity for each stratum and its weathering condition are summarized approximately as follows (Refer to Plates G8 to G11, G16, G17, G19 to G21).

	Seismic velocity (km/sec)
Top soil and talus deposit	0.3 - 0.9
Debris of landslide	1.3 - 3.0
Matrix layer of Ermenek Ophiolitic Melange	
Highly weathered rocks	1.5 - 2.0
Moderately weathered rocks	2.8 - 3.0
Slightly weathered to fresh rocks	3.5 - 3.9
Görmel formation	
Highly weathered rocks	1.5 - 2.0
Moderately weathered rocks	2.8 - 3.0
Slightly weathered to fresh rocks	3.5 - 3.9
Limestone blocks in the Melange	
Highly weathered rocks	1.8 - 2.3
Moderately weathered rocks	3.8 - 3.9 (3.1 - 3.3)
Slightly weathered to fresh rocks	5.0 - 5.2 (4.5)

Note: (3.1 -3.3) and (4.5); power house site

4.2 Laboratory Test

The laboratory tests were performed for the limestone (Nadire formation) in the damsite I-C for the purpose to estimate foundation rock strength. 18 samples in total were taken from the boreholes SK-302, 307 and 313, which are all slightly weathered to fresh rocks. The test items are unconfined compressive strength and super sonic wave test. The test results are summarized in Table A4. The average, maximum and minimum values of these test results are as follows.

	Compressive strength (kg/cm^2)	Supersonic wave velocity (m/sec) Vp	Vs	Dynamic Poisson's ratio	Dynamic Elast. modulus (kg/cm^2)
Average	731	6,236	3,025	0.35	718,749
Maximum	1,366	6,500	3,261	0.38	837,107
Minimum	288	5,847	2,808	0.33	612,854

The values of unconfined compression test results are in rather wide range, between 288 to 1,366 kg/cm^2. The values in each hole are summarized as follows. Bulk specific gravity is 2.68 g/cm^3 on average.

Compressive strength (kg/cm^2)	SK-302 (nos)	SK-307 (nos)	SK-313 (nos)	All holes (nos)	
More than 1,000	1	0	4	5	(28%)
1,000 to 800	0	0	0	0	(0%)
500 to 800	2	3	5	10	(56%)
200 to 500	1	1	1	3	(16%)
less than 200	0	0	0	0	(0%)
Average (kg/cm^2)	727	533	812	731	

(Note: SK-302 and 307; drilled in pre-F/S stage)

4.3 Rock Classification and Estimated Rock Properties

The rock classification applied to the Ermenek Project is shown in Table A5, and the rock classification (K.Kikuchi Et.al.) which is used in Japan in general is shown in Table A6. The comparison between each classification is shown in Table A7, in which estimated rock properties for each classification are described.

According to the above-mentioned investigation and test results and observation results of boring core samples, the rock properties for limestone in the damsite I-C and the power house site, and marl of Görmel formation in the damsite I-B in slightly weathered to fresh rocks are estimated to be as follows.

Limestone in damsite I-C and power house:

Rock classification	: CH to B (Hard rock)
Compressive strength	: 700 - 800 kg/cm^2
Static modulus of elasticity	: 80,000 - 200,000 kg/cm^2
Cohesion	: 40 - 50 kg/cm^2
Internal friction angle	: 40 - 55 degrees
Static Poisson's ratio	: 0.25 - 0.3

Marl (Görmel formation) in damsite I-B:

Rock classification	: CM (Soft rock)
Compressive strength	: 100 - 200 kg/cm^2
Static modulus of elasticity	: 10,000 - 15,000 kg/cm^2
Cohesion	: 10 - 15 kg/cm^2
Internal friction angle	: 30 - 40 degrees
Static Poisson's ratio	: 0.15 - 0.2

Limestones in the other formations have similar properties to those of the damsite I-C. The matrix layers of the Ermenek Ophiolitic Melange are formed by medium hard (sandstone, conglomerate, ophiolitic rocks, etc.) to soft (schist, siltstone, etc.). These rock properties are varied in wide range, and are CL to CH class rocks in Table A7.

CHAPTER 5. SITE GEOLOGY

5.1 Damsite I-B

5.1.1 Geological condition

The geological profile of the damsite I-B is shown in Plate G4.

The left bank of approximately above 550 meters in elevation is formed by very thick debris of landslide. The alternative dam axis I-B is located at a little upstream side of these very thick debris area. The thickness of debris is 23.8 meters at SK-202 (hole mouth EL.613.62 m) on the proposed dam axis, while it is about 60 meters at SK-209 (hole mouth at EL.619.68 m), which is located at about 150 meters downstream from SK-202 in the thick debris area. The foundation rock is marl of Tertiary Görmel formation.

The river section is about 600 meters in width. The surface of this section is covered by Quaternary deposits, such as terrace deposit, talus deposit and riverbed deposit, with thickness of 10 to 30 meters. The foundation rock is marl.

The right abutment is formed by mainly marl, with some intercalation layers of thin sandstone and conglomerate of Görmel formation. Depth of fresh and stable rock is estimated to be 35 to 40 meters in general. The fresh rocks are seen below 37.7 meters in depth in the borehole SK-212.

Any major fault structures could not be found in the proposed damsite.

5.1.2 Engineering geology for damsite I-B

(1) Foundation rock

The foundation rocks are mainly marl in the whole section of the dam, which are typical soft rocks. Slightly weathered to fresh rocks of marl correspond to CM class, and moderately to highly weathered rocks correspond to CL to D class (rock classification of K.Kikuchi Et.al., refer to Table A7). The rock properties are described in Chapter 4.

A test adit was excavated in pre-F/S stage at EL. 560.62 meters near the boreholes SK-212 and 213, in the right bank, downstream of the proposed dam axis I-B. In the test adit, slightly weathered to fresh marls are seen in the section deeper than 15 meters. These have sufficient strength and be appropriate for a 100 meters high dam foundation (refer to Fig. A9). The estimated depth of slightly weathered to fresh rocks is shown in Plate G4.

On the left abutment, very thick landslide debris is distributed widely. While the thickness of debris is about 24 meters at the borehole SK-202, it is estimated to be increasing towards higher elevation of the slope, especially in the area above EL.600 meters. Practically, the maximum crest elevation of dam in this site had better be lower than approximately EL.600 meters. If crest elevation exceeds this level, the excavation volumes will be drastically increased.

(2) Permeability

There will be no serious problems about water leakage after impounding of the reservoir with a dam at this axis, because the foundation rocks are all low pervious marl, sandstone and conglomerate of Görmel formation on the proposed dam axis.

(3) Foundation treatment

Although the foundation rocks are almost low pervious marls, groutings for curtain, blanket and consolidation will be required along the dam axis below impervious core zone and spillway structures for treatment of permeability and uniting the foundation rocks. The required foundation treatment works would be as follows.

Curtain grouting:
Two rows, and hole intervals of 2 - 3 meters in each row. Maximum depth below riverbed section will be about half the dam height (50 meters when dam height is 100 meters), and minimum depth in both abutments will be about 20 meters.

Blanket grouting:
Two to three rows in both upstream and downstream areas of the curtain grouting, and hole intervals of 2 to 3 meters in each row. Hole depth will be 5 to 10 meters as a rule.

Consolidation grouting:
Similar density and depth to those of the blanket grouting will be required for the spillway structures.

(4) Slaking

Marls, even in fresh rocks, have a tendency to slake easily by exposing to air. Therefore, some special care will be required during embankment works of impervious core zone.

5.2 Damsite I-C

5.2.1 Geological condition

(1) Base rock

There are three alternative sites, I-Ca, I-Cb and I-Cc in the narrow gorge as shown in the geological map (Plate G3). The geological condition of each alternative site is shown in the above-mentioned geological map and geological profiles (Plates G4, G5 and G6), and seismic exploration profiles (Plates G8, G9, G10 and G11).

All the three alternative sites are located in an upper Jurassic - Cretaceous limestone block in the Ermenek Ophiolitic Melange. This limestone is hard and massive rocks but has many solution cavities which are seen on the rock surfaces in the gorge and in the drilling core samples.

(2) Fault structures

Three fault structures were confirmed in the limestone block through the field reconnaissance as listed below (Refer to Plate G3).

Fault	Location	Strike and dip
F-1	At the upstream end of gorge	N30°W/vertical
F-2	At the middle part of gorge	N70-90°W/50-75°SW
F-3	Branch of F-2 on the left bank	N60-70°W/65-80°SW

The fault F-4 (N30°W/vertical) at the downstream end of the gorge, could not be confirmed clearly in the field, while this could be estimated from the topographical features. The faults F-1, F-2 and F-3 have openings and/or fractured zone of 0.5 to 1.0 meter in width.

According to the results of borehole SK-310, there may not be major fault structures below the riverbed. The SK-310 shows that:

(A) Rocks below the riverbed are formed by very hard, massive and fresh limestone, without any fracturing, in the whole length.

(B) Permeability is very low, almost less than 1.0 Lugeon, according to the tested section of 40.0 - 160.0 meters in hole depth (EL.480 - 360 m).

(C) Solutions were not seen in the whole length.

(3) Groundwater level

Groundwater level in the left bank rises towards mountain side along the boundary between limestone and matrix of Melange. In the right bank, it is almost horizontal but, in general, slightly rises towards mountain side with such exceptions as slightly lowers towards mountain side within limited local areas (Refer to Plate G3).

Groundwater levels measured in the boreholes SK-302 and 303 from January to December 1989 in the left bank, and SK-304, 305, 306 and 308 in the right bank from April 1989 to April 1990 are summarized together with the river water level in the Fig. A8. The measurement point of river water level is located at just entrance of the gorge as shown in Plate G3. The figure shows the following features.

Right bank:

(A) From April to September 1989, water levels in SK-304, 305 and 308 show drew down from EL.507-508 meters to EL.504-505 meters, while river water level stayed almost constant, at about EL.506 meters. Water level in SK-306 was about EL.509 meters in September.

(B) From October 1989 to April 1990, river water level showed rather irregular elevation due to rain, at about EL.506 meters to nearly EL. 510 meters. Water levels in boreholes SK-304, 305 and 308 showed generally rising from about EL.504-505 meters to about EL.506-507 meters.

Water level in SK-306 was rather constant, at about EL.508.5 meters.

(C) In general, water level of SK-304 showed the lowest in the whole period observed, second was SK-305, third was SK-308 and the highest was SK-306 in general. These suggest that the water level in the area surrounding the SK-304 may be the lowest and it may rises towards the river and towards the mountain.

Left bank:

(A) Water level of SK-302 was about EL.550 meters from February to April, and nearly EL.540 meters from May to December.

(B) Water level of SK-303 was about EL.620 meters in all the above period.

(C) River water level was the same as that in the right bank, which was about EL.506 meters in general.

(D) These two holes showed much higher levels than that of river water level in the whole period observed.

(4) Rocks and permeability condition in the right bank

The rocks and permeability condition in the right bank is shown in Plates G12 and G13. All the boreholes drilled in the right bank suggest that:

(A) In the section from the ground surface to EL.500 meters, oxidation (weathering) and solution are commonly seen in all the holes, and permeability shows very high Lugeon partly.

However these decrease gradually towards the hole bottom, and decrease much in the section approximately below EL.350 meters in SK-304, EL.320 meters in SK-306, EL.500 meters in SK-307, EL.400 meters in SK-308, EL.470 meters in SK-313. In SK-305, weathering and solution are seen in the hole section down to the hole bottom (EL.323.57 m). Also in SK-314, these are seen till hole bottom (EL.276.38 m).

(B) The Lugeon test results are summarized in Table A8, and approximately as follows.

Lugeon value	Percentage of all Lugeon values (%) Above EL.500m	EL.500m to EL.400m	Below EL.400m
Less than 1.1	54	60	80
1.1 - 10.0	25	33	11
10.1 - 50.0	9	3	0
More than 50.0	1	0	0
Gauge P.= 0	11	4	9

(Gauge P.: Gauge pressure)

The gauge pressure zero means that the Lugeon values of the sections tested will be rather high in general. In the low elevation area below EL.400 meters, zero gauge pressure was recorded at 11 measurements (9 %), all in the SK-314. Other Lugeon values of 112 measurements in this low elevation area all showed figures less than 10.

In the section from ground surface to about EL.500 meters, those test results which showed more than 10 Lugeon or zero gauge pressure were about 20 %. In the section below EL.500 meters, those were less than 10 %.

(C) Clayey zones are seen in the section between 314.90 meters (EL.393.64m) and 332.50 meters (EL.376.29m) in SK-306, and between 369.50 meters (EL.357.23m) and 389.50 meters (EL.337.23m) in SK-314. These clayey zones are estimated to be filling materials of old cavities, which are very well compacted and without any openings judging from the drilling records.

Consequently, it can be said that the area from the ground surface to the EL.500 meters is formed by highly karstic limestone; the area below EL.500 meters may be formed by low permeable limestone in general.

However there are some possibility of existence of solution cavities approximately up to a level of EL.400 - 350 meters in general and partly up to EL.320 meters, while most of these cavities are estimated to be old and filled by well compacted clayey materials completely. Below these elevations, such possibility may decrease much.

(5) Geological condition of alternative damsite

(A) Damsite I-Ca

The damsite I-Ca is located near the upstream end of the gorge. The geological profile is shown in Plate G5.

(a) Foundation rocks
The foundation rocks are a limestone block of the Nadire formation in the Ermenek Ophiolitic Melange. Ophiolitic rocks are distributed in the area below EL.360 meters at the riverbed (SK-310), and below EL.475 meters in the right bank (SK-307).

(b) Major joint direction
On the both abutments:

Ja: NS-10°E/vertical :	Interval of 1-3 meters. Continuity is low.
Jb: N70°E-EW/90-70°NE:	Interval of 1-3 meters. Continuity is medium.
Jc: N40-80°E/30-40°NW:	Interval of 10 meters or more. Continuity is high.

In the test adit (Adit along dam axis):
Joints having high continuity

N35-40°E/60-65°N;	section 9-10m (Jc)
N10°E/50°W ;	section 16-17 m
N30-40°E/20-35°N;	section of 25-30 m (Jc)
N70°W/65°N ;	section of 37-38 m

Joints having low continuity but high frequency

N5-15°E/50-60°W

N30-80°W/70-90°E

(Refer to Fig. A9)

(c) Weathering and stability of abutment

From riverbed to approximately EL.580 meters: Weathering seems to be of low grade, especially in the area below approximately EL.520 meters. Both banks are formed by almost vertical slopes, without any deposits, and are in stable condition. All joints are in tight condition.

Many cavities (1-3 meters in width) are seen along the joint Jc in the area above EL.520 meters. The area below EL.520 meters, such cavities are very rare (observation from window of test adit).

Above EL.580 meters:

The rock surface shows highly weathered condition in both banks. Many open joints are seen.

The wall slope of the left bank is about 60 degrees from horizontal direction, and 40 degrees on the right bank in the elevation range between EL.580 meters and EL.650 meters. The wall slopes are partly covered by thin (1 to 2 meters) talus deposit. Above EL.650 meters it is 10 to 20 degrees in both banks. Both banks seem to be in stable condition except surface zones.

(d) Permeability

According to the Lugeon test results in the boreholes SK-310 and 307, permeability was very low (almost zero Lugeon) below the riverbed and below EL.510 meters in the right abutment.

In the right abutment, the area from ground surface to EL.510 meters, rock is karstic limestone with very high permeability.

Solution cavities are seen along the above-mentioned joints and/or irregularity on the rock surface in the whole abutment area. Large and serious fault structures for the dam construction were not observed on the rock surface and in the boreholes SK-307 and 310.

(B) Damsite I-Cb

The damsite I-Cb is located at about 70 meters downstream from the I-Ca site. The geological profile is shown in Plate G6.

(a) Foundation rocks

Almost similar to that of the I-Ca damsite.

(b) Major joint directions

Almost similar to that of the I-Ca damsite. Continuous and notable joints are N60-90°W/50-60°N (Jd-1) at around EL.640 meters on the left bank and N80°E/40°N (Jc-1) at around 600 meters on the right bank.

(c) Weathering and stability of abutment

From riverbed to approximately EL.600 meters: Weathering seems to be of low grade, especially in the section below approximately EL.520 meters. Both banks are formed by almost vertical slope, without any deposits. The left abutment is in stable condition, but the shoulder part of the right bank near EL.600 meters seems to be unstable judged from the existence of joints Jc-1 and others.

Above EL.600 meters:
Rock surface shows highly weathered condition in both banks. Many open joints are seen.

In the elevation range between about EL.600 and EL.660 meters on the left bank, the wall slope is 30-40 degrees from horizontal direction in the lower half and 60-70 degrees in the upper half. Above EL.660 meters, it is about 20 degrees.

On the right bank, it is about 40 degrees in the lower half and about 70 degrees in the upper half in the elevation range between EL.600 meters and EL.670 meters.

Both banks are partly covered by thin (1 to 2 meters) talus deposit. The left bank is in stable condition except surface zones. The right bank seems to be unstable because of Joint Jc-1.

(d) Permeability
Similar to that in the I-Ca damsite.

Solution cavities are seen along the abovementioned joints and/or irregularity on the rock surface in the whole abutment area except the area below EL.520 meters where these are very rare. Large and serious geological structures for the dam construction were not observed on the rock surface.

(C) Damsite I-Cc

The damsite I-Cc is located at the middle portion of the gorge, about 400 meters downstream of the I-Cb site. The geological profile is shown in Plate G7.

(a) Foundation rocks
The foundation rocks are limestone of the Nadire formation in the Ermenek Ophiolitic Melange.

(b) Major joint direction

Je: N10-30°W/vertical:	Intervals of 1-3 meters. Continuity is low.
Jf: N70°E-EW/90-70°NE:	Intervals of 1-3 meters. Continuity is high.
Jg: NS-30°E/50-70°NE :	Intervals of 10 meters or more. Continuity is high.

(c) Weathering and stability of abutment
From riverbed to approximately EL.650 meters: Weathering seems to be in low grade. Both banks are formed by almost vertical slope, without any deposits, and are in stable condition.

Above EL.650 meters:
Rock surface shows moderately weathered condition in both banks.

Slopes are about 55 degrees from horizontal direction on the left bank and about 70 degrees on the right bank in the elevation range between EL.650 meters and EL.720 meters, partly covered by thin (1 to 2 meters) talus deposit. Above EL.720 meters, it is 15 to 30 degrees on both banks. Both banks seem to be in stable condition except surface zones.

(d) Permeability

In the right abutment, the Lugeon tests in the borehole SK-313 show that high pervious karstic limestone exists in the section from ground surface to EL.475 meters. The section below EL.475 meters is low pervious limestone. There are no records in the left abutment, however, it is assumed to be similar condition to that in the right abutment.

Solution cavities are seen along the above-mentioned joints and/or irregularly on the rock surface in the whole abutment area, especially in the middle part (EL.550 to 650 m). The SK-313 show that solution is very rare below EL.475 meters.

Large and serious geological structures for the construction of dam are not observed on the rock surface and in the borehole SK-313. The faults F-2 and F-3 exist at about 100 meters upstream, but those dips show toward upstream by 50 to 80 degrees.

5.2.2 Engineering geology for damsite I-C

(1) Foundation rocks

According to the result of seismic exploration, seismic velocity is estimated to be 5.0 km/sec in slightly weathered to fresh rocks which correspond to B to CH class of rock classification (K.Kikuchi Et.al.), and these will be appropriate for the foundation of 200 meters high arch dam (refer to Table A7). Rock properties for limestone in this area are mentioned in Chapter 4.

In the test adit which is located at EL.520 meters, rocks are very tight and massive condition, while weathering is seen on joint surface in the section deeper than about 7 meters. The section from wall surface of gorge to 7 meters deep are formed by moderately weathered rocks, with some open joints.

According to the results of seismic exploration, rocks having 5.0 km/sec velocity are distributed approximately deeper than 20 to 40 meters from ground surface in general. Consequently, the excavation depth of foundation rocks for all the three alternative sites is estimated to be as follows:

Both abutments near crest elevation: 30 - 40 meters.
Riverbed elevation : 5 - 10 meters.
(Refer to Plates G8 and G9)

(2) Foundation treatment

Consolidation grouting and curtain grouting will be required for the dam foundation to treat permeability and to unite the rocks for all the alternative damsites as follows.

(A) Consolidation grouting

In the whole dam foundation area, with hole intervals of 2 - 4 meters and depth of 10 - 20 meters as a rule.

(B) Curtain grouting

According to the results of Lugeon tests in the boreholes, permeability of rocks decreases gradually towards deeper portion. The permeability condition of the foundation rocks in the surrounding area of all the alternative damsites is summarized as follows (Refer to Plate G3).

Limestone:

Area from ground surface to about EL.500 meters:
    High pervious and karstic limestone.

Area approximately between EL.500 to 400 meters:
    Low pervious limestone, but possibly having solution cavity in some places.

Area below about EL.400 meters:
    Low pervious limestone, with very low possibility of cavity existence.

Area near boreholes SK-316 and 314
    Rather high pervious limestones and cavities are seen for the depth until about EL.350 - 320 meters.

Ophiolitic rocks and marl (Görmel formation):
    Low permeability in fresh rocks, without solution cavities.

Considering the above-mentioned permeability conditions, the following curtain groutings will be required for all the alternative damsites.

Grouting area:
In the right bank, the depth of grouting will be down to approximately EL.400 meters in general except in the area near boreholes SK-306 and 314 where it will be down to about EL.350 meters. The horizontal end portion of curtain grouting will be penetrated into marl layer of Görmel formation.

In the left bank, limestone becomes thinner towards upstream. In the area below limestone, rocks are low pervious ophiolitic rocks. Then, the bottom of curtain grouting will be raised along the bottom surface of limestone, and will be penetrated into ophiolitic rocks (Refer to Plate G12).

Grouting pattern:
In the section close to the dam foundation, both abutments for 100 to 200 meters horizontally from the end of dam crest, the required grouting pattern will be two rows, with hole intervals of 2 meters in each row. The grouting will be done until obtaining Lugeon value of less than 1.0 in this grouting area.

In the other sections apart from the dam, it will be one row, with hole intervals of 2 to 4 meters. In this area, the purpose of grouting will be to fill up rather big solution openings which would cause serious leakage after impounding of reservoir. Then the target of treatment will be 10 lugeon or more.

Grouting gallery:
The curtain grouting will be performed mostly from tunnel galleries. The intervals of gallery will be approximately 40 to 50 meters vertically. The

size of gallery will be decided based on the anticipated size of drilling equipment, which will be more than 3.0 meters high and more than 2.5 meters wide.

(3) Treatment of fault F-2

In the I-Cc damsite, treatment of the fault F-2 which is located in the right abutment will be required by means of grouting, concrete replacement, etc., while the fault will be treated by the curtain grouting for the depth until EL.400 meters.

(4) Drainage system

The drainage system by drainage holes will be required in the downstream side of all the curtain grouting area for the purpose to decrease uplift pressure for the dam body and abutment foundation, and also for the monitoring of leakage. The drainage holes will be drilled mostly from the grouting gallery. The intervals of drainage holes will be about 10 meters horizontally in the area close to the dam, and 10-20 meters in the other areas apart from the dam.

(5) Surface excavation

As a general rule, excavation slopes are designed to be no steeper than any steeply inclined discontinuity along which sliding may occur. Where a slope is undercut by steeply inclined discontinuity formed by two or more sets of joints, etc., support may be required to prevent sliding.

The supporting methods will be designed based on the rock mass quality and distribution of discontinuity as investigated by mapping and drilling.

5.3 Power House

5.3.1 Geological condition

The geological condition of the power house area is shown in Plates G15 and G16. The results of boreholes SK-102 and SK-108b are as follows.

SK-102:

(1) The section from the surface to 156 meters in depth (EL.469 m) is formed by limestone, which is very hard and massive in the deep portion.

(2) The section between 156 meters (EL.469 m) and 263.2 meters (EL.361.8 m) is formed by the matrix layer of Ophiolitic Melange, which is alternation of schist, sandstone and rarely limestone. Schist is mostly silty to clayey, friable with high schistosity.

(3) The section between 263.2 meters (EL.361.8 m) and 286.55 meters (EL.338.45 m) is formed by fresh, hard and massive limestone.

(4) The section from 286.55 meters (EL.361.8 m) to the bottom, 341.6 meters (EL.283.4 m), is formed by black, medium hard sandstone, which also are matrix of Ophiolitic Melange.

(5) Groundwater level, which was measured during drilling works, was approximately 120 meters (EL.505 m) deep.

SK-108b:

(1) The section from 5.0 meters (EL.479.49m) to 27.0 meters (EL.458.82m) is highly to moderately weathered limestone.

(2) The section from 27.0 meters to 196.75 meters (EL.299.31m) is slightly weathered to fresh limestone in general. The core samples show partly highly cracky zones, such as the section between 103.0 meters (EL.387.40m) and 126.90 meters (EL.364.94m).

(3) The section from 196.75 meters to 201.2 meters (EL.295.12m) is schist of matrix layer of Ermenek Ophiolitic Melange.

5.3.2 Location of power house

According to the above-mentioned investigation results, the matrix layers are D, CL to CM class rocks. Such rocks are generally unsuitable for the construction of underground power house. Rocks having appropriate condition are only limestone in this area.

The location of the power house is proposed in the elevation range between about 312 meters and 355 meters.

The borehole SK-108b show that the depth of limestone bottom is 196.75 meters which is EL.299.31 meters. In the borehole SK-106 located on the Erik river, the limestone thickness is 186.7 meters, and the bottom of limestone is lower than EL.182.85 meters. These bottom elevations at SK-108B and SK-106 are lower than that of the proposed bottom of the power house (EL.312 m).

According to the above-mentioned results, the power house can be probably placed in limestone block in the area between the SK-108B and SK-106, while more investigation to confirm the bottom elevation of limestone block will be required (Refer to Plate G15).

5.3.3 Strength of limestone

The limestone is Nadire formation in the Ermenek Ophiolitic Melange, and it will correspond to CH to B class in the rock classification of K.Kikuchi Et.al. (Refer to Table A7). According to the results of seismic exploration, the seismic velocity of slightly weathered to fresh limestone is estimated to be 4.5 km/sec. The details are described in Chapter 4.

5.4 Headrace Tunnel

5.4.1 Geological condition

The total tunnel length is about 9,000 meters and proposed tunnel diameter is about 6 meters. The estimated geology along the tunnel is schematically shown in Plate G14, and approximately as follows.

Entrance to 1,500 meters:
  Limestone of Nadire formation.
1,500 meters to 1,900 meters:
  Matrix layers of Ermenek Ophiolitic Melange.
1,900 meters to 2,400 meters:
  Limestone of Nadire formation.
2,400 meters to 2,700 meters:
  Matrix layers of Ermenek Ophiolitic Melange.
2,700 meters to 4,500 meters:
  Limestones of Taşdibi member, Ardiçli member and Saribayir member.
4.500 meters to 5,700 meters:
  Matrix layers of Ermenek Ophiolitic Melange.
5,700 meters to 6,800 meters:
  Limestone of Kükürce formation.
6,800 meters to 7,600 meters:
  Matrix layers of Ermenek Ophiolitic Melange.

7,600 meters to Surge tank:

Limestone of Azitepe formation and Nadire formation.

The tunnel will penetrate limestone for About 6,300 meters and matrix layers of the Ermenek Ophiolitic Melange for about 2,700 meters. These limestones are all blocks in the Ermenek Ophiolitic Melange, and the matrix layers of the Melange are composed of schist, sandstone, siltstone, conglomerate, ophiolite, serpentine, etc.

The above-mentioned limestones are all hard and massive rocks which correspond to CH to B class of the rock classification (K.Kikuchi Et.al) in slightly weathered to fresh rocks. The details are described in Chapter 4.

The matrix layers are medium hard to soft rocks which correspond to CM to CH class in fresh rocks. In the boring core sample, the rocks are in general highly cracky and partly fractured (Refer to Table A7).

Mineralogical study was performed for green schist and serpentinite by X-ray diffraction method for the purpose to examine swelling tendency of these rocks. Samples have been taken from outcrops near the power house and from the borehole SK-102. The results are summarized in Table A10. While only two samples were tested, the results suggest that these rocks have nil or very rare amount of minerals which have a swelling tendency (Refer to Attachment A4).

5.4.2 Groundwater condition along tunnel route

Groundwater level in limestone block of the Nadire formation at the entrance of the tunnel is almost similar to the river water level (about EL.500 m). Other measurement records are only in the boreholes SK-101 and SK-102 as follows.

SK-101:
Located at around middle portion of the tunnel route.
Water level in borehole: 20.0 meters (EL.960.61 m)

SK-102:
Located near power house.
Water level in borehole: About 115 meters (EL.500m).

Many springs can be seen along the tunnel route. The source of these springs is estimated to be limestone of Ermenek formation which is distributed widely in the higher elevation of the mountain in the southern area of the tunnel route. These springs suggest that groundwater level may be rather high in general, and rising towards southern mountain area being parallel to the ground surface. However, water levels in limestone blocks are supposed to be rather low in comparison with that in matrix layers, because of the karstic characters. If these blocks have no direct contact with limestone of the Ermenek formation, water levels in the blocks will be much low, even these show high elevation in the surrounding matrix layers.

5.4.3 Rock support

The rock supporting system during tunnel excavation will be made in general by combination of rock bolting, shotcreting with wire mesh and/or steel support. The type and density will depend on the quality of the rock mass. Considering the rock condition mentioned above, no support or light supporting system, such as rock bolt with wide grid (2 by 2 m grid) and thin shotcrete, will be sufficient for the limestone sections and rather heavy support will be required for the matrix layer sections.

5.5 Surge Tank and Penstock Line

5.5.1 Surge tank

The proposed headrace surge tank site is located in limestone of the Nadire formation which corresponds to CH to B class rocks of the rock classification (K.Kikuchi Et.al.) in slightly weathered to fresh condition.

No boreholes have yet been drilled in this site. According to the results of the seismic exploration line PB in the power house site which is located in similar limestone area to that in the surge tank site, seismic velocity and depth of velocity layers are estimated to be approximately as follows.

Surface to 10-20 m in depth:	0.7 to 0.8 km/sec
10-20 m to 25-50 m	: 2.0 to 2.3 km/sec
25-50 m to 80-100 m	: 3.1 to 3.3 km/sec
More than 80-100 m	: 4.5 km/sec

The bottom foundation of the surge tank may be slightly weathered to fresh rocks (4.5 km/sec). However, upper section of the surge tank site will be in such rocks as have seismic velocity of 3.1 to 3.3 km/sec, or 2.0 to 2.3 km/sec and correspond to CH to CM class in the rock classification (K.Kikuchi Et.al.).

5.5.2 Penstock line

The proposed penstock line will penetrate limestones of the Nadire formation in the uppermost and lowermost sections near the headrace surge tank and the power house sites, and matrix layers of the Ermenek Ophiolitic Melange in the middle section.

The rocks are estimated to be in slightly weathered to fresh condition for the whole section. Supporting system for tunnel works will be similar to that in the headrace tunnel (Refer to Sub-section 5.4.3).

5.6 Tailrace Tunnel

The proposed tailrace tunnel is about 1,750 meters in length and 6.1 meters in diameter. The geological conditions along the tunnel route and the outlet area are shown in Plates G17 and G18 respectively, and are approximately estimated as follows.

From power house to 1,050 meters:
    Limestone of Nadire formation.
1,050 meters to 1,200 meters:
    Matrix layers of Ermenek Ophiolitic Melange.
1,200 meters to outlet:
    Marl of Görmel formation.

The rock conditions of limestone and matrix layers are similar to that in the headrace tunnel, described in Sub-section 5.4.1.

Marl of Görmel formation is soft, massive and very low pervious rock, which corresponds to CM class rocks in fresh condition. Bedding of this layer is estimated to be horizontal to 5 degrees in dipping and to have a strike towards north.

According to the results of seismic exploration line PC, the seismic velocity of each layers is as follows (Refer to Plate G17).

Limestone:

Ground surface to 1-5 m in depth	:	0.3-0.4 km/sec
1-5 m to 15-20 m	:	2.0-2.2
15-20 m to 50-65 m	:	3.1-3.3
Deeper than 50-65 m	:	4.5

Matrix layers and marl:

Ground surface to 1-5 m in depth	:	0.3-0.4 km/sec
1-5 m to 8-15 m	:	0.8-0.9
8-15 m to 15-30 m	:	1.5-1.7
15-30 m to 45-70 m	:	2.8-2.9
Deeper than 45-70 m	:	3.6-3.7

Rocks in all the tunnel section are slightly weathered to fresh limestone (4.5 km/sec), fresh matrix layers and marl (3.6-3.7 km/sec) except the outlet portion.

Rock condition in the outlet portion was investigated by the borehole SK-107. This hole shows that weathered rocks are seen in the section until 9 meters in depth. The section below 9 meters is formed by fresh marl, while Lugeon values are rather high, being more than 10 in general and partly more than 50, until 26 meters. Lugeon values below 20 meters are less than 1.0. And the seismic exploration results show that the outlet part for about 60 meters in horizontal length is 1.5-1.7 to 2.8-2.9 km/sec velocity zone near the tunnel elevation (Refer to Plate G18).

Ground water level, which was measured in the SK-107 during drilling works, is 15 to 16 meters in depth.

Supporting systems for tunnel excavation works are supposed to be similar to that in the headrace tunnel for the section of limestone and matrix layers. For the marl section, a medium to heavy supporting system will be required because of its slaking tendency. A heavy supporting system will be required for several 10 meters in length from the outlet towards upstream.

5.7 Landslide Area

5.7.1 Geological condition

The geological profiles along the seismic exploration lines LA, LB and LC are shown in Plates G19, G20 and G21 respectively, and are featured as follows.

(1) Debris zone of landslide is formed by mostly rock fragments and blocks of chalky marl, which is very highly pervious and loose deposit.

(2) The deepest sliding planes (bottom of landslide zone) may exist in the surface zone of marls, which are in the depth between 128 meters (EL.587.51 m) and 155 meters (EL.560.51 m) in the borehole SK-214, and between 115 meters (EL.633.78 m) and 130.8 meters (EL.617.98 m) in SK-220.

(3) Groundwater levels were seen just above the marls in the whole boreholes, and were 112.45 meters deep (El.636.33 m) in SK-220 at the end of September 1989. These facts suggest that marls are always in saturated condition by groundwater. The water levels measured in SK-201, 202, 217, 218, 219 and 220 from January 1988 to December 1989 are shown in Fig. A8.

5.7.2 Slope stability

The major conditions which cause landslide in relation to reservoir impounding are generally described in Japan as follows (M.Watari, President of Japan Landslide Society).

(1) Topography and geology show features of historical landslide activities.

(2) Steep slope inclination.
Many cases of landslides in the past have slope inclination of more than 20 degrees in general.

(3) Rapid drawdown speed of reservoir surface.
Most of landslides occurred during drawdown of reservoir water level with a drawdown speed of more than 2.0 meters/day.

While the topography and geology in this site actually show historical landslide features, the slope inclination is about 10 degrees on average, and also an expected drawdown speed of the reservoir water level is much low, about 10 centimeters/day or less, in comparison with the 2.0 meters/day above.

Consequently, it can be judged that no serious and huge volume of landslide will occur during and after impounding of the reservoir.

5.8 Erik Intake Weir, Diversion Tunnel and Power House

5.8.1 Erik intake weir

The weir site was first conceived at about 2 km upstream from the confluence of the Ermenek river and the Erik river. However it was shifted to an upstream point about 4 km upstream from the confluence, because a large scale and active landslide exists on the upstream reach of the first site. The new site is located at an immediate upstream point of the landslide. The geological condition of the intake site is shown in Plate G22.

The intake site is formed by hard and massive limestone of Kükürce formation in the Ermenek Ophiolitic Melange. The foundation rocks well outcrop in both abutments of the weir, which are mostly in moderately weathered condition and highly weathered and loosened conditions partly on the surface. The moderately weathered limestone corresponds to CH class in the rock classification, and has sufficient strength for the weir foundation. Excavation of 1 to 3 meters in depth will be required for the weir construction.

The riverbed is covered by sand and gravel layers of several meters in thickness. Removal of such deposits will be required for the weir construction.

5.8.2 Erik diversion tunnel

The tunnel of 3,580 meters in length with section of 2.2 x 2.3 meters will connect the intake weir to the head-tank. The tunnel route is located in rather deep portion of mountains to detour the active landslide area. The geological condition, which is estimated by geological reconnaissance survey, is schematically shown in Plate G23, and is featured as follows.

Intake weir to 800 meters:
Limestone of Kükürce formation.
800 meters to 1,250 meters:
Matrix layers of Ermenek Ophiolitic Melange.
1,250 meters to 1,400 meters:
Limestone of Kükürce formation.
1,400 meters to 1,650 meters:
Matrix layers of Ermenek Ophiolitic Melange.
1,650 meters to outlet:
Limestone of Azitepe formation.

Limestones are hard rocks, partly well bedded, and correspond to CH to B class rocks. Matrix layers are composed of well bedded alternation layers of sandstone, conglomerate and siltstone in general, which are soft (siltstone) to medium hard (sandstone and conglomerate) rocks in rather stable condition, with rare fracturing. These layers correspond to CM to CH class rocks (Refer to Chapter 4).

Required supporting systems for tunnel works are estimated to be light to medium for the matrix layer sections, and non-support or light for the limestone sections.

5.8.3 Erik power house

Boring investigation was not performed in this area. The power house site is located in the Görmel matrix layers of Ermenek Ophiolitic Melange. The surface is covered by thin talus (1 to 3 meters) deposit. Foundation rocks are alternation of sandy limestone and siltstone, rarely schist, sandstone and conglomerate, which are highly weathered in the outcrops and well bedded but irregular. Irregular bedding may suggest that the surface zone creeps along the slope. Strength of these rocks will be sufficient as foundation for the power house.

In the upper slope of the power house, approximately above EL.740 meters, limestone of Azitepe formation well outcrops, and is hard and well bedded (about EW/40^{O}N). The proposed headtank and outlet of the diversion tunnel is located in the limestone. No geological difficulty could be found for construction of such structures in this area.

5.9 Reservoir Area

5.9.1 General condition

The geology of the reservoir area is composed mostly of sedimentary rocks, such as marl, sandstone and conglomerate, of Tertiary Görmel formation, and partly matrix layers and limestone blocks of the Ermenek Ophilitic Melange. These rocks except limestone blocks are generally low pervious without any solution cavities. Therefore, there are no leakage problems in all the area formed by the Görmel formation and matrix layers of the Melange.

Limestones are seen only in the damsite area and in the backwater area. Limestone in the damsite will be treated by the curtain grouting. Possibility of leakage from limestone block located in the backwater area will be described in Sub-section 5.9.2.

Any serious slope stability problems could not be found in all the reservoir area, because, slopes in the surrounding area of the reservoir show very gentle inclination in general although many historical sliding topographies were seen, such as those on the left bank of the I-B damsite.

5.9.2 Leakage from backwater area of reservoir

According to the drilling core observation of SK-215 and SK-216 and site reconnaissance, the geological condition of the limestone block in the backwater area of the Ermenek reservoir is as follows (refer to Plates G24 and G25).

(1) Alternation layers (siltstone, sandstone, claystone and limestone) of about 100 meters in thickness are distributed on the right bank area of Ermenek river with bedding of approximately EW/20-40^{o}N.

(2) The alternation layer is low pervious in general, and groundwater level rises towards the south along the upper boundary of the alternation layer on the right bank of the river. Many springs can be seen along the existing logging roads and in the higher elevation areas than that of the roads (higher than El.700 meters).

In the right bank of the river, this layer will act as a barrier against groundwater flow towards south direction.

(3) The northern area of the river is formed by very wide mountainous plateau of elevation higher than 1,000 meters, where the limestone block is surrounded by the matrix layers of the Ermenek Ophiolitic Melange. The matrix layers, which are low pervious in general, are widely distributed towards the north, and are covered by Miocene karstic limestone. Also, many springs are widely distributed in this area. This area may have very high potential of groundwater.

(4) In the upstream of this limestone block, Nadire and Kapiz springs (refer to Chapter 3) are located, which suggest that the area has very high potential of groundwater. Also thrust fault which may be located just upstream of these springs with south-north trend would act as a barrier against groundwater flow towards west direction.

Consequently, the groundwater levels in both the banks are estimated to be higher than the proposed reservoir water level in general. Therefore, possibility of leakage through this limestone will be very low.