REPUBLIC OF KENYA

LAKE BASIN DEVELOPMENT AUTHORITY

SONDU RIVER MULTIPURPOSE DEVELOPMENT PROJECT

VOLUME IV (PART 1)

SUPPORTING STUDY REPORT FOR HYDROPOWER PLAN

DECEMBER 1985

JAPAN INTERNATIONAL COOPERATION AGENCY

NAIROBI OFFICE
P.O. BOX 50572
NAIROBI KENYA

TOKYO HEAD OFFICE
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TOKYO JAPAN

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1/ International Seismological Centre

2/ Cornell (1968), Bulletin of the Seismological Society of America, (BSSA), Vol. 58, p-1586

3/ Trifunac and Brady (1975), BSSA, Vol.65, p-147

Chapter 1. INTRODUCTION

The geological and geotechnical survey and investigations for the Sondu River multipurpose project were carried out from January to February and from June to November in 1984. The first survey includes the field reconnaissance referred to the available geological maps of the scale at 1/250,000 and topographic maps of the scale at 1/50,000 to confirm the geological formation in the project area.

Based on this survey, the programmes for field investigation in the second period which would be rendered to the local engineering firm were worked out including tender documents. In March 1984, the succeeding tenderer, the H.P.GAUFF KG, Nairobi was selected among four bidders, to complete mobilization for the works before the second visit of the JICA team.

In the middle of June, the following works; the seismic exploration, the core drilling with water pressure test, test pitting and laboratory tests were commenced at the site by the GAUFF under the direction of the experts of the JICA team. In parallel with the above mentioned works, the geologist of the team started the preparation of geological map covering the damsite, reservoir area, headrace, power station, prospective rock quarry and other associated work site.

By the end of November, the following works had been completed:

Geological mapping	65 km^2
Core drilling	970 m in 24 holes
Water testing	87 stages in 15 holes
Laboratory rock testing	10 specimens
Seismic exploration	12,050 m along 12 lines.

The results of those works are presented in this volume.

Chapter 2. GENERAL GEOLOGY

2.1 General

At the survey in the project area including damsite, reservoir area, power station site, and irrigation area, a geological map of 1 : 125,000 (GEOLOGY OF THE KISUMU DISTRICT by E.P. SAGGERSON, B. SC., F.G.S.) and a geological map of 1 : 250,000 produced by the Ministry of Water Development as part of the final report on PRELIMINARY HYDROGEOLOGICAL INVESTIGATION were referred to.

The former one is exclusively used for the determination of the geological age and the stratigraphy in this area. Core boring and seismic exploration works were programmed to confirm the geological condition at the proposed damsite, the headrace tunnel, the power station site and the quarry site.

The geological maps of the damsite and the associated work site, and the reservoir area were produced through the intensive surface geological exploration based on the topographic sheet 1 : 10,000. Figure 2.1 shows a geological plan of the project area.

2.2 Physiography

The Sondu River in the Project Area runs through peneplain of the elevation 1,400 m to 2,000 m, which is covered by post-cretaceous, pre-miocene erosional surface. The Sondu River in this reach flows east to west. Many bends of the river were observed attributed to the action of small faults which are to be, more or less, closely related to the formation of the Kavirondo Rift Valley during pleistocene times, with its predominantly east-west faulting.

Shortly before the river leaves the Nyakach escarpment, it turns the direction to the northwest, and continues to flow down the escarpment and across a flat plain of pleistocene alluvial deposit, until it enters the waters of the Winam Gulf.

At the piedmont of the escarpment, near the location of the proposed power station, extensive gulley erosion is taking place, due to rush of stream flows originated from the escarpment.

2.3 Stratigraphy and Structure

The project area can be divided into two parts by a prominent Nyakach escarpment running almost east-west. The primary dam structure, spillway, intake structure and quarry site are located on the peneplain south of the escarpment, an upthrown block formed by tensional forces and normal faulting. The structures such as surge tank, penstock are designated to be located at sloping hilltop and on the slope of the escarpment. While the power station is to be located on the downthrown graben. The normal fault between two tectonic blocks is known as the Kendu fault.

The "graben" plain, called Kano Plain is bounded to the north also by normal faulting and a huge escarpment called the Nyando escarpment. The Kano Plain is bounded by the escarpments of granodiorite in the north and the south, the lake Victoria in the west and the east the Quaternary lake sediment of which ground level rises eastward in the east. Collectively, the structures forming the Kavirondo Rift Valley and offshoot of the Great Rift Valley of East Africa are pleistocene in age.

The stratigraphy is shown on Table 2.1 (Geological Legend). The general geology of the catchment area of the Sondu River(scale 1 : 250,000) is presented on Figure 2.2. The main geological formations which occur in the project area, are explained in the order of younger ages in the following.

1) Recent

The Recent deposits include hill-wash, alluvial flats talus deposits consisting of sand, gravels, lateritic ironstones and black cotton silts, occurred in the depressed Kano Plain and the peneplain in the Nyakach escarpment.

Wide-spread hill-wash accumulation occurs at the foot of the Nyakach escarpment and along the flat shaped creeks on the peneplain. The thickness varies widely by locations, ranging 2 to 20 m, and accumulated strata is well compact. They stand rather uniform strata consisting chiefly of silt at the foot of the escarpment and talus deposits consisting of sand and gravels on the peneplain. Erosion by the streams flowing off the steep hills has cut into the deposits to depths of up to 10 m, and in some places, it reaches to bedrock.

Alluvial flats form the vast Kano plain, into which several rivers flow and carry a large quantities of silt and sand.

Red brown lateritic ironstones widely spread on the bedrock above EL. 1,400 m on the peneplain, forming a cover to the large part of the district over the Nyanzian and Bukoban rocks and locally over the granodiorite rock. The thickness ranges 0.5 m to 6.0 m and the soil is mostly classified as red soil type but is locally cemented.

2) Pleistocene

The Pleistocene includes lake deposits and river deposits forming semi-consolidated layer of clay, sand and gravel. The strata of the Pleistocene is overlaid with top soil and hill-wash, and its outcrop is rarely seen. The Pleistocene deposits are to a large extent seen as lake sediments under the top soil of the Kano plain, and to a small extent on the alluvial terrace along the Sondu River. Mostly they are horizontally stratified and are of soft rock type, where fine-grained deposit is well consolidated but coarse-grained deposit of sand and gravel is not well consolidated.

3) Tertiary

Tertiary volcanic rock involves chiefly phonolite, of which lava flow is seen on the Nyabondo plateau overlying the granodiorite on the right bank of the river near the Sondu village. The rock with dark bluish grey in colour is seen as hard block rock, but is easily fractured with hammering.

4) Upper precambrian Bukoban system

The widespread Bukoban System and the Nyanzian system widely extend in the south western part of the project area. This involves mainly andesites, dacites and basalts, and locally quartzite and cherts. To a large part near the Sondu River, are seen greenish blue non-porphyritic and fine-grained basalts. This system has a hard rock with joints spaced at several ten centimeters in the fresh part but spaced a few centimeters in the weathered part.

5) Intrusives

The intrusives consist mainly of granitic rocks such as granite, granodiorite and diorite, being regarded as batholith. Dolerite, aplite or basalt is occasionally seen as dyke to a small extent. Among granitic rocks, Miriu granodiorite is dominant rock which belongs to the age between Bukoban and Nyanzian, and extends widely from the Sondu village to the outfall of the Sondu River. The upper portion of the rock mass forms slight relief topography on the peneplain but the river channel of the lower reach forms steep shaped valley by erosion. The Miriu granodiorite is in general bluish grey hard rock but varies considerably in colour, grain size and texture by location.

6) Nyanzian roof pendant

In association with the intrusion of the Miriu granodiorite into the Nyanzian System, xenolith or roof pendant is formed. This occurs from the right bank downstream of the lower storage damsite to the left bank, extending further to the upper reach on the left bank. The Nyanzian roof pendant may exist at many places inside the Granodiorite rock mass at the damsite and the headrace tunnel, which was not detected at this investigation. The rock facies consist mainly of darkish grey hornblende gneiss with significant schistosity. The fresh rock is rather hard but so susceptible to weathering that the outcrop rock is broken apart to plate-like pieces, a few millimeters to a few centimeters thick with light hammering.

7) Nyanzian system

The Nyanzian rocks are basalts, andesites and rhyolites with major and minor tuff development. In general the rocks are hard but more or less sheared, moreover of which surface is highly weathered and jointed closely. These rocks are seen in the upstream reaches of the Ngoino and south of the Opanga.

8) Basement system

The Basement System is seen in the eastern edge part of the Kano Plain and in the far upstream reach of the Sondu River. The rock facies consist of gneiss, schists and quartzites.

2.4 Faulting

In the project area, two prominent faults, namely Kendu fault and Sondu fault, are seen, which were active in Tertiary times but re-established as a zone of movement in Pleinstocene times. The Kendu faults extend over a distance of about 13 km or more in east-west direction with many associated minor branch faults. To the east it has a drop of more than 300 m but diminishes rapidly as it goes westwards and at Kendu is no greater than 100 m. It consists of several parallel faults, forming a shear-zone 90 m wide at maximum and steeply dipping northerly. In the granodiorite zone of the Nyakach escarpment, the drop ranges between 100 m and 200 m. The Sondu faults consist of a lot of faults with north-east to south-west direction, extending from the vicinity of Sondu village to the upstream along the Sondu River. They, in many places, cut into Phonolite of Bukoban System.

Chapter 3. SEISMICITY

3.1 General

The seismic study on the Sondu/Miriu project was carried out based on the following data and reports:

- Earthquake records in the western Kenya (Data collected through I.S.C.[1])
- A Catalogue of felt earthquakes in Kenya by I.S. Loupekine, 1971
- Preliminary report on the Homa bay earthquakes by I.S. Loupekine, 1968
- Engineering report on Kiambere Project.

We requested to I.S.C. the seismicity searches around the proposed damsite bounded by 5.38°S - 4.62°N, 29.85°W - 39.85°E, in which the I.S.C. Historical Hypocentre File 1904-84 and the I.S.C Comprehensive Catalogue File 1968-81 were used. The results of these computer services were presented in DATA BOOK-2.

3.2 Earthquake Records around the Proposed Damsite

The I.S.C. produced the following lists.

List 1 Contents and hypocentres found from the Historical Hypocentre File for the region concerned. And the distances from the hypocentres to the site and values of theoretical intensity and ground acceleration at the damsite. (It is notified by I.S.C. that these values must be treated with great caution as they are computed with the formulae derived from data with great scatter and for ground conditions prevailing in the southern California which, of course, is not globally true.)

List 2 Line printer plot of the region, in which magnitude and location of the earthquakes are reproduced.

List 3 Hypocentres found in the region of the site from the I.S.C. Catalogue File.

The list of earthquake records are summarized in Table 3.1.

3.3 Evaluation on Seismic Coefficient

The distinctive earthquake records are selected among the data available for assuring the probable ground acceleration at the dam site with three kinds of formulae conventionally used. In addition, the probable ground acceleration was deduced from the Seismic Zoning Map of Kenya and the World Map of Natural Hazards. These are all presented on Table 3.2 and Figure 3.1.

Earthquake record A	Earthquake record B
1928.1.6	1972.9.10
Magnitude 7.0	Magnitude 4.6
Distance 209 km	Distance 32 km

From those data, it might be concluded that the probable ground acceleration be 50 to 60 gals.

1) I.S.C. (International Seismological Centre)

Intensity on the Modified Mercalli scale at specified position is calculated, using the following formula:[2/]

$$i = 8.0 + 1.5\ m - 2.5\ \ln r$$

where m = magnitude
r = focal distance in km
ln = natural logarithm.

Peak horizontal acceleration in cm/sec^2 (ah) is calculated, using the following formula:3/

$$\log ah = 0.014 + 0.30\ i.$$

2) Estiva's method

The expected acceleration at the proposed damsite is given by the following Estiva's equation:

$$a = (5{,}000 \times \exp(0.8 \times M))/(HD + 40)^2 \quad \ldots\ldots (3)$$

$$HD = \sqrt{D^2 + Z^2} \quad \ldots\ldots (4)$$

$$D = 2 \times 3.14 \times R\ (d/360) \quad \ldots\ldots (5)$$

$$d = \cos^{-1}(\sin(y_0) \times \sin(y) + \cos(y_0) \times \cos(y) \times \cos(x - x_0)) \quad \ldots\ldots (6)$$

$$R = Ry^2 \sqrt{(1 - e^2 \times \cos^2 y)} \quad \ldots\ldots (7)$$

$$e = C/Rx \quad \ldots\ldots (8)$$

$$C = \sqrt{Rx^2 - Ry^2} \quad \ldots\ldots (9)$$

where a : Peak ground acceleration in cm/sec^2
M : Magnitude
HD : Hypocentral distance in km
D : Distance between damsite (x_0, y_0) and epicenter (x,y)
Z : Depth of earthquake in km
R : Radius of earth in km : Rx = 6,378 and Ry = 6,356
d,e,C : Parameters.

3) Kawasumi's method

Intensity in JMA (Japan Meteorological Agency) scale is given by the following formula.

$$S = 2M - 4.6052 \log R - 0.00183 R - 0.307 \quad (\text{when } R \geqq 100 \text{ km})$$

$$S = 2 (M - \log X) - 0.0166X - 3.9916 \quad (\text{when } R < 100 \text{ km})$$

where S : Intensity in JMA (Japan Meteorological Agency) scale
M : Magnitude in Richter scale
R : Distance from the epicenter in km
X : Distance from the focus in km.

The expected acceleration is given by the following formula:

$$A = 0.45 \times 10^{S/2} \quad (\text{when } S \leqq 5.5)$$

$$= 20 \times 10^{S/5} \quad (\text{when } 5.5 < S < 7.0)$$

A : Acceleration in cm/sec^2

S : Intensity in JMA.

4) Maximum acceleration to be expected in a probable return period of 100 years

Predictions have been made of the statistical return periods of various magnitude seismic events in the Sondu area.

Frequency of earthquakes in each grade of Mercalli Scale during the period of 1912 to 1982, of which all data come from I.S.C, is converted into frequency in 100 years. From the relationship between the intensity (i) and the cumulative number of frequency (Nc), the expected maximum intensity, that is, the expected maximum acceleration in a probable return period of 100 years is shown in Table 3.3.

Plotting the above on the coordinates i - log Nc as shown in Figure 3.2. The following equation is obtained by the least square method:

$$\log Nc = 2.405 - 0.382\, i.$$

For the case of Nc = 1, the expected maximum intensity in a probable return period of 100 years is estimated at i = 6.3. According to the method adopted by I.S.C, this intensity corresponds to the ground acceleration 80 in gal.

3.4 Concluding Remarks

Based on the available data presented in DATA BOOK-2, a review of the seismicity of the area was made to assess the earthquake coefficient to be used for dam design. Most records show that the area is in a low risk zone. And the computation of the expected ground acceleration indicates 50 to 60 gals, which correspond to seismic coefficient $k \doteqdot 0.05$ and 80 gals for the maximum credible earthquake, which correspond to seismic coefficient $k \doteqdot 0.08$.

Most engineers in the United States, who use a pseudo-static method for seismic stability analysis, adopt some empirical value for the design seismic coefficient, that is, 0.05 to 0.15 (H. Bolton-Seed & G.R. Martin, 1966). The Kiambere project, now under construction, which is located in the same low risk zone as the Sondu/Miriu project site, adopts K = 0.10 as the operating basic earthquake which corresponds to the design earthquake.

The seismic coefficient k = 0.05 could be adopted in such a low risk zone as in the project site. However, it is prudent for the feasibility design purpose to adopt k = 0.10 as coefficient of earthquake in due consideration of the maximum credible earthquake to occur once in 100 years.

Chapter 4. GEOLOGICAL INVESTIGATIONS

4.1 Geological Mapping

The surface exploration was first carried out in the whole project area with aid of the topographical map (1:125,000), to learn the overall geological condition in the area concerned. And the proposed sites such as dam, tunnel, power station and reservoir area were intensively explored and mapped with aid of the topographical map (1:10,000) and the geological map (1:50,000) compiled from the available geological map (1:125,000) published by E.P. SAGGERSON, B. Sc., F.G.S. Geologist.

The geological map as shown on Figure 4.1 was produced in making full use of stratigraphic information obtained in drilled holes and surface exposures of outcrop. The geological sections of main structures such as dam, intake, headrace tunnel and power station were presented on Figures 4.2 based on the drilled holes and the seismic exploration. The quality classification of rock is based on Table 4.1.

4.2 Drilling and Water Pressure Testing

The drilling holes (Drilled logs are referred to DATA BOOK-2) were put down on the seismic traverse lines except BD-10 and BD-13. All the holes were drilled vertically except BD-4 and BD-5, where the holes were put down at the angle of 50 degrees to the horizontal to detect vertical faults, if any. All the boreholes with a total length of 970 m, are located as follows:

- BD-1, BD-2, BD-3 and BD-4 on the right bank, and BD-5, BD-6, BD-7 and BD-8 on the left bank along the axis of the lower storage damsite, also on the seismic line A.

- BD-9 and D-10 on the right bank near the axis of the upper intake damsite, while BD-3 and BD-9 are on the seismic line B.

- BD-11 and BD-12 on the left bank near the river channel, also on the seismic line C.
- BD-13 on the right bank, downstream of the lower storage damsite.
- BS-1 and BS-2 on the right bank along the axis of the spillway, also on the seismic line E.
- BT-1 and BT-2 near the intake structure, on the right ban, also on the seismic line N.
- BT-3 on the half-way of the headrace tunnel, also at the cross point of the seismic lines L and Q.
- BT-4 at the surge tank site and BP-1, BP-2 and BP-3 in the power station area, also on the seismic line M.
- BQ-1 and BQ-2 in the quarry site on the right bank, also on the seismic line F, while BQ-2 is located at the cross point of the seismic lines F and I.

The boring depth and elevation were all presented on Table 4.2. The results are shown in Figure 4.3.

The water pressure tests (refer to DATA BOOK-2) were carried out for the boreholes numbered BD-1 to BD-13 and BS-1 & BS-2. The results are presented on Table 4.3.

For reference, the methods of drilling and water pressure tests are briefly described here-in-after. The drilling was carried out by three Craelius D-750 and one Rodio rotary diamond-core drilling rigs using impregnated diamond bits of 146, 101, 86, 76 and 66 mm diameters. An average flush of 60 litres per minute was used for drilling through rock and slightly more was used for unconsolidated materials, especially sand. Digging with six inch diameter auger was made to start a borehole on several occasions where overburden posed a problem. The use of drilling mud (bentonite, or barite and silica) was restricted to holes in which no water pressure tests were to be performed. Drilling conditions were generally favourable with very little caving in boreholes and few instances of water loss, thus a minimal amount of casing was used. However, in several boreholes, caving did pose a significant problem, and at times these holes were cemented in the course of drilling through them. While the borehole was being drilled, closed hole permeability test was conducted in vertical sections averaging approximately 5 meters in length. This was accomplished by using a single inflatable pneumatic packer blocking the hole while water was pumped in to attain pressure of 1, 4, 7, 10 kg/cm^2 in an ascending and descending progression. Each pressure value was sustained for 10 minutes before moving to the next step and the total discharge recorded.

4.3 Seismic Exploration

Twelve seismic exploration traverses, with a total length of 12,085 m, were made to amplify results on thickness of alluvium, weathered granodiorite and fresh granodiorite as obtained from core drilling, and to obtain average bedrock velocities. The traverses are located as follows:

- Traverse A, B, C and E in the lower storage damsite
- Traverses F, H and I in the quarry site
- Traverses N, L and Q in the intake and the headrace tunnel
- Traverses M and P in the power station.

1) Seismic refraction prospecting

a) Profile line arrangement

Seismic refraction profile lines were arranged as shown in DATA BOOK-2. These were performed by the local consulting engineers, H.P. GAUFF KG under the supervision of JICA engineer and LBDA engineer. Their work quantities are listed on Table 4.4.

b) Field operation

The arrangement of shots and detectors was planned to be laid out on a line (profile shooting). Before the field recording began, ground surface profiles were surveyed and shot, and detector stations were marked by stakes.

In one cycle of operation, the distance range was arranged in such a manner that six or seven shots of an interval of 50 m or 100 m were picked up by 20 detectors which were spread at an interval of 5 m or 10 m. The shot locations and detector spreads in one operation cycle were moved progressively to provide complete coverage over each refraction profile line.

Main instruments and materials used are shown on Table 4.5.

c) Time-distance plot and profile interpretation

Travel time of the seismic wave (primary wave) was read from the recording paper with an accuracy of 1/10,000 second, and plotted on the time-distance graph. From this time-distance relation, the profile of velocity layers was deduced by the Hagiwara's method. The time-distance curves and the profile interpretations are attached in this volume (DATA BOOK-2).

d) Evaluation of seismic refraction prospecting

The geology in the project area consists mainly of top soil and talus deposit as unconsolidated layer and granodiorite as bedrock. The bedrock of granodiorite is locally intercalated with gneiss and/or dolerite to a small extent.

The results of seismic refraction prospecting are shown on the seismic refraction profile with time-distance plot and interpretation. The speed layers chiefly obtained are classified into six groups, each of which can be assumed to correspond to the geological condition shown in Table 4.6.

6TH speed layer (5.6 to 6.0 km/sec)

This speed layer of which value is the highest among the values measured in this investigation, corresponds to the basement rock into which no weathering is recognized to develop. This rock designated as granodiorite, is very hard and only slightly jointed, indicating more than 1,000 kg/cm^2 in unconfined compressive strength, so that the rock is very much suitable for the foundation of the dam and the other structures as well as for the tunnel excavation.

5TH speed layer (3.7 to 3.9 km/sec.)

This speed layer of which rock retains most of the same rock texture as 6TH speed layer, but is slightly jointed and weakened by weathering, corresponds to very slightly weathered rock. The rock itself is fresh and hard. The seismic wave speed of this layer is likely to decrease due to some development of joints.

The rock, indicating low permeability, is suitable for the foundation of the dam. In case of tunnel excavation, some corruption of small scale rock fragment may be anticipated but it may not cause a big problem.

4TH speed layer (2.6 to 2.8 km/sec.)

This speed layer of which rock is more weakened by weathering than that of 5TH layer as well as more jointed, corresponds to slightly weathered rock. The rock is locally hard and fresh, but as a whole is jointed and some open cracks are observed in minor parts. Some special foundation treatment will be required in case of large scale rock excavation or of construction works on the slope. However, the rock is rather good for the foundation of the normal structures. Appropriate leakage prevention measures are required for the dam foundation due to high permeability.

3RD speed layer (1.7 to 1.8 km/sec.)

This layer of which rock is much more weakened by weathering than that of 4TH layer as well as much more jointed, corresponds to highly weathered rock. Open cracks which are observed at many places, are filled with clay. The weathering is well developed into the rock.

Strict leakage prevention measures will be indispensable for the dam foundation and adequate supports for the tunnel excavation.

2ND speed layer (1.0 to 1.2 km/sec.)

The layer consists of the rock which is severely weathered as well as significantly jointed or of talus. This is treated as unconsolidated layer in engineering works, even if some traces of rock origin are recognized.

1ST speed layer (0.3 to 0.6 km/sec.)

This layer consists of top soil and talus.

4.4 Test Pitting

Thirteen test pits were dug by hand to a maximum depth of 5 m. These test pits were explored for the sources of the earthfill material, and numbered from TP. No.15 and S/006 were used for the sources of sand material, where only sampling was made from the sand deposits.

The details are discussed in CONSTRUCTION MATERIAL STUDY (Appendix II, Volume IV).

4.5 Laboratory Testing

All the materials sampled for the earthfill, the sand and the quarried rock were hauled to the Gauff's laboratory in Nairobi. The results are discussed in CONSTRUCTION MATERIAL STUDY (Appendix II, Volume IV).

Chapter 5. SITE GEOLOGY AND ENGINEERING GEOLOGICAL ASSESSMENT

5.1 General Site Geology

5.1.1 Structure

The geological structure at the site investigated is a plutonic intrusion of intermediate rock commonly known as the Miriu Granodiorite. In some places, small dykes of Dolerite run through the pluton in east-west and north-south directions, hinting that these directions may have been the pattern of faulting during pre-cambrian times. It is possible that the tensional forces during the pleistocene rifting may have exploited these old lines of weakness resulting in the more recent faults which generally trend in the same directions as the dykes.

Most of the granodiorite exhibits a marked sub-vertical (50° - 80°) foliation, vividly revealed by the darker amphibole minerals. Outcrops in the area show that the major dip direction is northerly. The foliation probably derives from the intrusive process itself, since orthogenic activity during Bukoban times and later have shown to be minor and the granodiorite does not appear to be metamorphosed to any great extent.

In terms of techtonic structures, the project area can be divided into two regimes. The primary dam structure, spillway, intake, headrace tunnel and quarry site are located on the peneplain extended south of the Nyakach escarpment, an upthrown block formed by tensional forces and normal faulting. Surge tank, penstock and powerhouse structures are located just down below the escarpment on the surface of the downthrown graben. The normal fault between these two tectonic blocks is known as the Kendu fault.

5.1.2 Lithology

The Miriu Granodiorite intrusion predominantly consist of greyish white, coarse-grained granodiorite, but rock cores obtained by drilling, revealed some variation in colour, texture, and petrology within the pluton. Foliated coarse-grained granodiorite of varying colours of blue, mottled green and black and deep red was observed. Although the variations in colour have not been investigated through petrographic analysis, they are assumed to be the result of contamination and alteration of feldspars through, chloritization, kaolinization, replacement, ferrous solutions and similar processes. Alternatively, the green colour may indicate the presence of minerals such as diopside.

While logging the rock cores, it was frequently noticed that the rock changed its texture and structure as well as colour, usually with all the changes being continuous and gradational, and often these varying lithologies alternated repeatedly. For convenience, all blue, green, or dark grey fine-grained, non-foliated rocks were termed DIORITE.

Besides the petrological variation within the Miriu Granodiorite, some of which could be attributed simply to magmatic differentiation, another lithology, petrologically unrelated to the Granodiorite was encountered. Bluish black and fine-grained, the rock consisted almost entirely of amphibole with some quartz banding, and was thus considered to be an amphibolite, ever though its texture was not very schistose, but rather like that of a gneiss.

Much of this rock can be seen at the surface a few hundred meters downstream of the damsite, although its occurrence in the boreholes was rare. Only BS-2 showed a significant amount of this rock at depth, that being only seven meters thick. In the core log sheet this rock type is referred to as AMPHIBOLITE GNEISS.

The amphibolite gneiss is a xenolith of Nyanzian metamorphosed basalts into which the granodioritic intrusion invaded. In other words, as the intrusive magmatic fluids penetrated through the Nyanzian country rock, pieces of the metabasalt broke off and travelled upwards with magma. What is not clear is how much alteration of the amphibolite was due to contact metamorphism with the intrusion, and how much can be attributed to the Kavirondian orogeny. However, it should be noted that the formation of amphibolite is often associated with thermal metamorphism.

For engineering purposes, all the lithologies are basically the same in terms of strength and stability, except for the amphibolite gneiss which is weaker and easily parts along cleavage planes when struck lightly with a hammer.

5.1.3 Jointing

Most of the joints in the granodiorite were of a sub-vertical nature and the majority of them belonged to two major sets, one set trending in the north-south directions and the other in the east-west directions. In addition, there was a minor set of sub-horizontal joints trending 080 dipping to the north-north-west. When examining the rock cores, it was observed that many joints were consistent with the sub-vertical amphibole foliation with slight dips to the north. It was noticed on highly and moderately weathered cores, a scaly, pitted appearance on the outside of the core. This was due to the "falling out" of amphibole minerals, which are not as stable as quartz or plagioclase at surface conditions, thus leaving lines of weakness. This may be the reason why many of the joints are in parallel places to the foliation. It should also be noted that the coarse-grained rock in the area appeared to be more susceptible to weathering than the finer grained homogeneous rocks, and the joints may not be related to foliation in such cases.

The majority of joint surfaces were smooth, with about 20% to 30% of the total number recorded being rough. Most joints had at least some limonite and pyrolusite staining and kaolinization of the surfaces was quite common. Chlorite and sericite were also seen. In some bore-holes, crushed and gouged rock was observed, indicating some movement within the rock mass. On the whole, this was not very common, being restricted to small zones in a few boreholes (with the exception of BT-4, BP-2 and BP-3). Despite the fact that most joints were numerous and stained, water seepage, as revealed by water pressure tests, seems to be rather low. This may be due to the possibility that many joints are discontinuous, having been sealed by mineralization.

A higher degree of jointing appeared in the amphibolite gneiss, being much more closely spaced than in the granodiorite. The main joint system was sub-vertical trending N40°W - N30°W.

5.2 Reservoir Area

Bedrock consists mainly of granodiorite with minor gneiss, basalt and rhyolite. In the main part of the proposed reservoir area, granodiorites predominantly occur along the river up to near Sondu village where Precambrian basaltic rock occurs on the left bank.

The extent of weathering in the granodiorite formation is moderate and no large scale land sliding is probably expected after filling of the water, except small collapse on the river banks and terraces.

The geological map for the reservoir area is presented on Figure 2.1.

5.3 Lower Storage Damsite

The geology of the damsite and associated works site is shown on Figure 4.1 while geological section A-a (Figure 4.2) is a typical profile across the valley.

The main geological features of the lower storage damsite are:

- bedrock consisting of moderately strong intrusive rocks.

- on the whole, bedrock is of granodiorite with minor diorite; excavation depths to hard rock (which is suitable for the foundation of the impervious core of a rockfill dam) range up to 5 m, averaging about 3 m and excavation depths to fresh and hard rock (which is suitable for the foundation of a concrete dam) range up to 8 m averaging 5 m.

- bedrock is generally covered by thin top soil and/or talus of gravelly sand which is up to 1 m thick in average on both banks, but possibly up to 5 m in places on the right bank above EL.1425m.

- granodiorite outcrops in many places along the lower bank of the river channel while gravel-sands occur in quite limited localities and scarce in quantity.

Geologically the site is considered suitable for either a concrete type dam or a rockfill type dam. The former is recommended to be founded principally on the hard and fresh rock, involving the excavation of slightly weathered rock designated as CM down to the bedrock which gives more than 2.6 - 2.8 km/sec in wave speed. The latter is recommended to be founded principally on the hard rock, involving the excavation of highly weathered rock designated as CL down to the bedrock which gives about 1.7 - 1.8 km/sec in wave speed. Foundation stripping in the shell zone will involve the removal of top soil, talus deposit and locally variably weathered rock. Because of the relatively thin layer of highly weathered rock, stripping beneath the impervious core is expected to be slightly deeper than for the remainder of the embankment.

Foundation excavation for the concrete type dam will involve the removal of top soil, talus deposits and weathered granodiorite down to the hard and fresh rock. Over the most part of the foundation, average excavation depth will be roughly 5 m. However, excavation depths of up to 15 m are anticipated in the flat area above EL. 1,425 m on the right abutment. Alternatively, such a method can be contemplated that excavation is stopped when is encountered the hard rock, from which consolidation grout be applicable.

Over the most part of the foundation in the impervious core zone, average foundation excavation down to the hard rock will be roughly 3 m. However, excavation depths of up to 10 m are anticipated in the flat area above EL. 1,425 m on the right abutment. In addition, large shape correction or dental concrete as part of foundation treatment is envisaged in the river channel portion due to irregularity of rock formation. Little deterioration of exposed surface will be anticipated after excavation due to air slacking.

Pressure testing of the drill holes indicated that the granodiorite rock is generally of fairly low permeability, in spite of the fact that the joints revealed by core drilling are numerous and stained. This may be due to the possibility that many joints are discontinuous, having been sealed by mineralization. However, there were in places losses of drilling water and high leakage rates of 20 to 100 Lugeons in the shallow portion of the ground down to a depth of 15 m in average. It is considered prudent to assume that a conventional curtain grout with subordinate blanket grout is necessary for both types of the dam. No groundwater was recognized throughout the drilling works.

5.4 Spillway

As shown in Figure 4.6, the geology along the proposed spillway alignment is mostly similar to that of the lower storage damsite, involving the same sequence of granodiorite. The top soil is rather thin, ranging 1 to 2 m in thickness. However, in the lower part, gneiss is found to be intercalated as BS-2 indicates.

The creek-like erosion topography indicated that the area was of fault valley, but the weathered layer designated by the low speed wave less than 1.8 km/sec. is found in the shallow portion within a depth of 10 m from the ground level. In the deep seated hard and fresh bed rock, around 15 to 20 m under the ground level, along the length of the seismic measuring points between E-380 m and E-720 m, six bands with 10 m in width of the low-speed wave of 3.0 to 3.6 km/sec are recognized. This indicates that the extent of weathering is rather variable with depth. It is not clear to regard this kind of weak zone as secondary product of faults crossing the E-line or as gneiss. According to the topography and the logging of BS-2, it may be regarded as fault.

Adjacent to the measuring point of E-100 m, two bands of low-speed wave which could be regarded as fault, are recognized but their direction of striking is not conclusive. These bands of low-speed wave ranged 2.4 km/sec to 3.6 km/sec are assumed to be considered as slightly weathered zone, which corresponds to CM in rock classification. Therefore, the bedrock is suitable for the structures concerned. However, it should be noted that the seepage path will be the shortest in the vicinity of the crest of the spillway structure and much attention be placed on the leakage preventive measure.

5.5 River Diversion

Geologically any significant difference is recognized between both banks in case of planning tunnel diversion. The right bank will be rather stable because of occurrence of prominent rock block. On the left bank, foliation is significantly developed so that it will form some weak zone.

The right bank upstream of the lower storage damsite is of terrace topography and the overburden is rather thick compared with the left bank. Therefore, geologically and topographically, the right bank is recommended for constructing diversion tunnel. But downstream of the damsite, gneiss outcrops at places and there occurs cracky rock in the weathered rock around the tunnel exit.

5.6 Upper Intake Damsite

The geology along the upper intake dam which is situated around 400 m upstream of the lower storage damsite, is similar to that of the lower storage damsite involving the same sequence of granodiorite rocks. However, the sub-surface conditions are inferred to a large extent because the sub-surface exploration in the upper intake damsite was of limited extent.

As a whole, fine to medium grained granodiorite is commonly seen as rather hard block. Large joints at a spacing of 1 to 3 m are commonly seen and platy joints at a spacing of 10 to 30 cm are also locally developed. These joints mostly running parallel to the river course predominantly dip to the left bank at an angle of 50°.

The bedrock of rather hard granodiorite is found around at EL. 1,380 m above which heavily weathered granodiorite overlies with a depth of about 3.0 m below the ground surface. In the riverbed and in the lower portion of the bank, are commonly seen rock outcrops. And the thickness of the top soil on the erosion terrace, which is gently sloped, will be within 1.0 m.

Foundation excavation for a concrete type dam will involve the removal of top soil, talus deposits and weathered granodiorite down to the fresh and hard rock zone or 1 to 2 m more. Over the most part of the foundation, average excavation depth will be roughly 5 m.

No surface evidence has been found to indicate such faulting as to affect a structure to be planned, but are seen at places minor faults without fracturing. Within the reach of 100 m upstream of the proposed intake dam, a series of rapids which form a fall a few meters high occurs due to those faults. Although the site seems to be affected more or less by these facts, it may not cause any major design problem.

There are losses of drilling water and high leakage rates during water pressure testing in the holes down to 5 m below the ground surface. The water tests indicate that slightly weathered to rather fresh granodiorite further below is of fairly low permeability, the Lugeon values being less than 3.

5.7 Waterway

The geology along the intake, the headrace tunnel, the penstock and the power station site, is generally similar to that of the lower storage damsite consisting mainly of granodiorite. However, various rock groups are seen at places over a length of about 4 km of the headrace tunnel connecting the intake to the power station. The intake structure is located at the right bank of the Sondu valley while the power station is at the foot of the escarpment.

The granodiorite, predominantly occurring along the alignment of the waterway structures, changes variably in grain size, that is, fine grained to coarse grained, as well as in colour, being locally intercalated with gneiss and/or dolerite.

Fresh granodiorite is a fairly hard rock, which shows more than 5.6 km/sec in seismic wave speed and also more than 1,000 kg/cm^2 in compressive strength.

In the deep portion of the ground through which headrace tunnel is to be driven, hard and rather fresh rock with little joint will be predominant over the most part but weathered and rather brittle rock with platy crack will be encountered in the vicinity of the fault.

It should be distinctively noted that weathering and crack are fairly developed deeply into the bedrock, that is, down to 30 to 70 m below the ground surface, along the escarpment originated in the Kendu fault where such structures as surge tank, penstock and power station are planned to be constructed. These faults run general in east-west direction, dipping northerly at the angle of 50 to 80 , so that the route of the penstock inevitably crosses the escarpment. However, the rock of the outcrop locally seen in the fault zone is fairly cracky but not fractured.

5.7.1 Intake Structure

Near the intake structure at the measuring points N-100 m to N-200 m along N-line as shown on Figure 4.5, the bedrock is assumed to be reached at a depth of 1.0 to 2.0 m below the ground surface, above which alluvial deposits of silty sand lie thinly. In the vicinity of the river channel, bluish green hard granodiorite occurs predominantly. However, at the portal portion of the intake located between the measuring points N-200 and N-550, the weathered layer of green coarse-grained rock is thick and some faults and rhyolite are locally seen. The bedrock is assumed to be generally rather brittle and slightly disturbed.

It would be necessary to take such protective measures as gunite on the excavated slope at the portal and concrete lining in the portal portion of the tunnel.

5.7.2 Headrace Tunnel (Section of the measuring points N-550 m to L-3,364 m)

It is possibly expected that the proposed tunnel is driven mainly through the fairly hard rock with more than 5.0 to 6.0 km/sec in seismic wave speed, but locally through the only slightly weathered zones with 3.7 to 3.9 km/sec.

In the boring cores which correspond to these low-speed wave zones ranged 3.0 to 3.5 km/sec, the core itself is rather fresh, with limonite stained joints. These rocks are CM to CH in rock classification. These low-speed wave zone may be regarded as fault or may be older granodiorite intercalated with gneiss.

It is generally anticipated that the proposed tunnel is driven across several wide faults. But as those faults are well reconsolidated and not severely affected by weathering due to thick overburden, much difficulty in tunnel excavation would not be encountered.

5.7.3 Surge Tank and Penstock (Section of the measuring points L-3,364 m to M-650)

The structures of surge tank and penstock are planned to be located in the zone between the shoulder of the escarpment and the foot of it, a number of small fractured traces along the Kendu fault are seen, across which the route of the penstock line runs inevitably. Those faults seem to be severely affected by weathering due to thin overburden. Especially around the shoulder of the escarpment where the surge tank is located, the fractured zone was recognized to develop up to a depth of 70 m below the ground surface. Therefore, it is quite necessary to take a special care in excavation of tunnel and shaft in this portion.

The core logging of BT-4 indicates that recovered cores are mostly of angular shape or of short cylinder type, of which joints are stained with limonite. Especially down to a depth of about 55 m from the ground surface, corruption of the borehole occurred at many places, seeming due to loose bedrock. Comparing the seismic wave speed with the rock classification for the bedrock at the lower storage damsite, very slightly weathered zone with 2.6 to 3.9 km/sec corresponds to CM to CH in rock classification. However, this area, even the same speed, corresponds to worse than CM or CL in parts. It will be difficult to evaluate the condition of the bedrock occurred along the escarpment with the seismic wave speed. This seems to be due to the existence of weak planes dipping steeply parallel to the escarpment slope. Despite this fact the bedrock seems to be rather stable as a whole. According to the drilling progress records, in which encounter of much corruption was reported, it will be considered that the relaxation of the bedrock progresses very fast in case of stress release by tunnel excavation.

The penstock is planned to be located just along the escarpment, of which surface is inclined at 30^{o} or more. Over the surface, rock boulder of granodiorite ranged 0.3 to 2.0 m in size are distributed. The bedrock will be encountered at a depth of 1 to 2 m below the ground surface but be highly weathered and very cracky. It is recommended that the rock anchors for the foundation of the penstock are constructed deep into the hard bedrock.

5.8 Power Station (Section of the measuring points M-650 to M-1380)

Gentle slope with an angle 5 to 10° is formed from the measuring point 700 m away from the escarpment. At the base of the escarpment, near the location of the proposed powerhouse, extensive erosion gulley consisting of medium to coarse sand and silt is seen, due to the rushed flow of the streams originating at the top of the hills. The thickness of the hillwash increases away from the foot of the escarpment. The deposit of hillwash is 1 to 2 m thick at the foot of the escarpment and 5 to 10 m thick in the vicinity of the power station site.

The bedrock consisting mainly of granodiorite, is disturbed so that it is characterized by the distinctive development of platy joints, involving pegmatites and quartz seams at random. In the vicinity of BP-2 and BP-3, the bedrock of which surface has irregular formation, is highly weathered and extremely jointed as well to a deep portion. The core log of BP-2 indicates that the RQD was zero at many places and the average RQD for the hole with a length of 10 m was the lowest of all the boreholes drilled except for BP-3 with a length of 30 m. Even when bedrock was reached at a depth of 27.25 m at BP-3, it was considerably broken and weathered. In taking into full consideration of these facts, more precise investigation with an emphasis on bearing capacity will be essential for shallow foundation, while for deep foundation, special measures to prevent falling down of the excavated slope would be indispensable.

5.9 Quarry Site

The quarry site is located on the right bank about 1.0 km downstream of the lower storage damsite, characterized by the gentle ridge extending in the northeast to southwest direction. The geological condition is similar to that of the lower storage damsite. The surface layer, 2 to 4 m in thickness is likely to include small to medium size fragments of granodiorite as well as silty sand originated in weathered granodiorite. Hard rock fragments with 0.1 to 2 m in size, are seen as outcrop at many places. The surface layer is underlain by the bedrock consisting mainly of granodiorite.

In the quarry site, core drilling was performed at two points, named BQ-1 and BQ-2 while seismic exploration was carried out along three lines, named Lines F, H and I.

As core logging indicates, hard and fresh bedrock of granodiorite is not reached until a depth of 19.75 m and 12.07 m in the borehole of BQ-1 and BQ-2, respectively. Until both depths, drilled cores are considerably weathered and are of sand and/or angular shape. Until both depths, drilled cores are of short cylindrical shape with 5 to 10 cm in length or of angular shape with less than 5 cm in length, while weathering is developed along the crack surface and some alteration is observed. The drilled core which is of angular shape, is so brittle that it is easily broken with light hammering. As a whole, the rock is coarse grained and foliation is well developed. These geological condition can be assumed to some extent by existence of xenolith.

The layer indicating 2.6 to 2.8 km/sec in seismic wave speed, corresponds principally to fresh and hard rock with joints spaced at 20 to 50 cm, classified as CH, while the layer with 3.7 to 3.9 km/sec corresponds to fairly hard and fresh rock with joints spaced at 30 to 80 cm, classified as CH to B. The joint surface of both rocks is slightly weathered locally.

It is unlikely that quarried rock be exploited as rock block in the surface layer with 1.7 to 1.8 km/sec in seismic wave speed because rock is weathered deep into the core and well jointed. It is assumed that rather hard rock to be used for rockfill and concrete aggregate could be exploited from the layer with more than 2.6 to 2.8 km/sec.

Chapter 6. RECOMMENDATIONS FOR FURTHER WORKS

A number of geological aspects affecting the various engineering structures of the Project will require further study in the next investigation stage.

A requirement will be the review of seismic risk. This will involve the study of an assessment methods of probable maximum seismic coefficient. In connection with this study, it should be re-examined whether the earthquake event dated on September 10, 1972 is really caused by or related to the movement of the Kendu fault.

Further geological work is anticipated in the dam foundation area. This will include the determination of stratigraphic structures with special emphasis on the weathering condition in relation with permeability. In addition, more precise geological mapping should be extended to cover the whole dam and spillway arrangement. Additional drilling in spillway area is also required to determine the thickness of the highly weathering layer. All this recommended work will enable the preparation of accurate bedrock contours which will be necessary to establish design levels for the spillway chute foundation as well as for the dam foundation.

It is recommended that the problem of the slope stability of the deep excavations to be anticipated in the vicinity of the intake, spillway crest structures and the power station shall be studied because of the thick weathered bedrock. In addition to stratigraphic data, further information is required on the orientation, location and spacing of joints and any other geological discontinuities in the vicinity of these deep cuts.

The following additional geological work is recommended in the next stage investigation:

Lower storage damsite

- Geological mapping on a scale of 1:1,000

- Depending on design requirements, drilling with water pressure testing may have to be done to provide additional information on stratigraphy and structure in close association with the seismic low speed layer as well as on the permeability of the foundation with 1.7 to 1.8 km/sec in seismic wave speed as a guide to grouting requirements and foundation excavation depths.

Upper intake damsite

- Drilling may have to be done to provide more precise information on the geological condition of the foundation; core drilling with water testing is required at four points along the dam axis at minimum.

Waterway

- The highly weathered area needs to be fully re-examined at the surge tank site; additional drilling and test adit are required to reliably determine their depth and areal extent and to define more precisely the existence and importance of the underlying fault.

Power station

- The area where several faults strike and weathering is well developed deep into the bedrock, should be fully re-examined for as realistic an assessment as possible of the weathering of the bedrock and of the excavation line of the foundation; comprehensive plan of core drilling is required to provide precise information for the detailed structural design.

Spillway

- The area where weathering is well developed deep into the bedrock, needs to be intensively re-examined; additional drilling, some of which is accompanied by water testing around the over-flow weir, is required to reliably determine the excavation depth and to provide precise information on the permeability of the over-flow weir foundation as a guide to grouting requirements.

<u>Quarry site</u>

- The area should be intensively re-examined with additional drilling and test aditting for as realistic an assessment as possible of the strata in close association with seismic wave speed zones, 1.7 to 1.8 km/sec and 2.6 to 2.8 km/sec.

TABLES

Table 2.1 Geological Legend

Age	Symbol	Description
RECENT	Al	Superficial Alluvium Sand, Gravels, Silt, Clay
PLEISTOCENE	Pl	pl Undifferentiated includes Lake deposits plt Mau and Londiani Ashes and Tuffs pl_B Londiani Matic Basalts and Basanites
TERTIARY	Tv	Tv Tertiary volcanics Kericho phonolite and Nyabondo phonolite
PRE CAMBRIAN	B	(BUKOBAN SYSTEM) B_A Rhyolites and tuffs, porphyritic felsites and Andesites B_q Quartzites with some cherts B_B Basalts and porphyritic basalts
PRE CAMBRIAN	Gn	Nyanzian roof pendant (Hornblende gneiss)
PRE CAMBRIAN	N	(NYANZIAN SYSTEM) N_R Rhyolite with intercalated tuffs (N_{Rt} and Agglomerates, Basalt, Na Andesites, Dasites and Tuffs
ARCHEAN	M	(BASEMENT SYSTEM) Undifferentiated gneiss, schists and quartzites, includes M_N-Nyanzian schists and M_K-Kavirondian schists.
	Gd	INTRUSIVES Granites (G_3 - Post Kavirondian (G_2 - Post Nyanzian Miriu Granodiorite (G - Undated
	D	Dolerites D_1 - D_3. Post Nyanzian

Table 3.1 List of Earthquake Records (1/9)

No.	Date			Epicenter				Depth	Magnitude	I.S.C		
	Year	Month	Day	Latitude		Longitude				Int.	cm/sec^2 Acc.	km Distance
1	1912	7	9	3.00	N	33.00	E		6.7	3.0	8	428
2	1913	9	16	6.00	N	36.50	E		6.2	0.8	2	730
3	1915	5	21	6.00	N	31.00	E		6.6	1.1	2	826
4	1924	7	1	1.00	N	32.00	E					353
5	1928	1	6	0.50	N	36.50	E	62	7.0	5.1	36	209
6	1928	1	10	0.50	N	36.00	E	62	6.0	4.3	20	162
7	1945	3	18	0.00	N	32.00	E		6.0	2.6	6	320
8	1949	10	1	7.50	S	30.00	E		6.0	0.0	1	951
9	1951	8	20	3.80	S	33.60	E					400
10	1951	11	1	4.00	S	35.25	E		6.0	2.0	4	400
11	1952	1	31	4.00	S	30.50	E		6.2	1.3	2	626
12	1952	4	4	4.00	S	29.60	E					706
13	1952	6	30	0.30	S	30.10	E					528
14	1955	7	22	1.42	N	30.52	E		5.0	0.0	1	522
15	1955	9	4	1.66	N	30.90	E		6.3	1.9	4	495
16	1955	12	15	6.25	S	30.99	E		5.0	0.0	0	775
17	1956	2	3	5.00	S	30.00	E		5.5	0.0	1	740
18	1956	4	4	4.98	S	35.44	E		6.5	2.2	5	510
19	1958	4	15	0.00	N	30.50	E		5.0	0.0	1	486
20	1959	1	23	3.00	N	35.00	E		4.9	0.5	1	376
21	1959	1	27	1.00	N	31.00	E		4.2	0.0	1	455
22	1959	3	8	3.78	N	36.94	E					517
23	1959	3	19	4.50	S	30.00	E					704
24	1959	5	10	3.00	S	34.50	E		4.2	0.1	1	290
25	1959	5	17	4.50	S	33.00	E		4.5	0.0	1	497
26	1959	6	19	0.17	S	29.38	E		5.4	0.1	1	609
27	1959	6	24	3.56	S	31.08	E		4.5	0.0	1	545
28	1959	8	9	0.50	N	29.00	E		5.1	0.0	1	658
29	1959	8	24	4.24	S	35.04	E		6.1	2.0	4	425
30	1959	10	25	4.83	S	35.64	E		5.2	0.3	1	497
31	1960	5	4	1.21	S	32.46	E		5.7	2.5	6	280
32	1960	9	22	3.40	S	29.10	E	29	5.6	0.0	1	720
33	1960	10	6	4.00	S	32.50	E					476
34	1964	1	3	3.00	S	35.00	E					288
35	1964	1	9	4.00	S	34.00	E					409
36	1964	3	5	3.40	S	35.00	E					332
37	1964	5	7	3.88	S	35.06	E	49	6.3	2.5	6	385
38	1964	12	21	3.67	S	29.93	E	10	5.6	0.2	1	655
39	1965	4	6	5.00	S	35.00	E					508
40	1965	4	28	4.00	N	35.50	E					491
41	1965	5	3	4.79	S	34.92	S	15	4.8	0.0	1	485
42	1965	5	12	4.83	S	35.00	E	12				490
43	1965	6	21	4.10	S	35.10	E	24	5.1	0.6	2	410
44	1965	11	26	5.30	S	35.60	E	49				548
45	1965	12	7	2.00	S	32.00	E					363
46	1966	1	1	5.00	S	35.00	E		3.9	0.0	0	508

Table 3.1 List of Earthquake Records (2/9)

No.	Date			Epicenter		Depth	Magnitude	I.S.C		
	Year	Month	Day	Latitude	Longitude			Int.	cm/sec^2 Acc.	km Distance
47	1966	1	12	4.00 S	30.00 E					670
48	1966	2	10	3.93 S	35.75 E	0				402
49	1966	2	15	4.00 S	35.00 E		3.6	0.0	0	398
50	1966	2	22	4.00 S	38.00 E		3.7	0.0	0	530
51	1966	2	25	4.50 S	35.40 E		3.5	0.0	0	457
52	1966	3	1	4.00 S	35.00 E		3.6	0.0	0	398
53	1966	3	9	2.27 N	31.42 E	35	5.4	0.6	2	482
54	1966	3	9	2.17 N	31.30 E	42	4.6	0.0	1	486
55	1966	3	18	0.10 S	30.60 E	0				474
56	1966	3	19	0.60 N	29.90 E	0				561
57	1966	3	20	0.81 N	29.90 E	34	6.0	1.1	2	566
58	1966	3	20	0.30 S	30.10 E		4.5	0.0	1	528
59	1966	3	20	0.30 S	30.10 E		4.1	0.0	0	528
60	1966	3	20	1.09 N	29.92 E	16	5.4	0.2	1	572
61	1966	3	20	0.30 S	30.10 E		4.2	0.0	0	528
62	1966	3	20	0.30 S	30.10 E		4.0	0.0	0	528
63	1966	3	20	0.82 N	30.05 E	4	5.1	0.0	1	550
64	1966	3	20	0.30 S	30.10 E		4.0	0.0	0	528
65	1966	3	20	0.30 S	30.10 E		4.1	0.0	0	528
66	1966	3	20	0.78 N	29.92 E	1	5.6	0.6	2	563
67	1966	3	20	0.30 S	30.10 E		4.0	0.0	0	528
68	1966	3	20	0.30 S	30.10 E		4.0	0.0	0	528
69	1966	3	20	0.30 S	30.10 E		4.0	0.0	0	528
70	1966	3	20	0.30 S	30.10 E		4.0	0.0	0	528
71	1966	3	20	0.30 S	30.10 E		4.1	0.0	0	528
72	1966	3	21	0.84 N	30.00 E	6	5.0	0.0	1	556
73	1966	3	21	4.00 S	35.00 E		4.4	0.0	1	398
74	1966	3	24	0.30 S	30.10 E		4.3	0.0	0	528
75	1966	3	25	0.86 N	29.90 E	0				568
76	1966	3	25	0.50 N	30.70 E	59	4.8	0.0	1	472
77	1966	3	25	1.00 N	30.40 E	33				518
78	1966	3	29	1.02 N	30.20 E	31				540
79	1966	3	29	0.30 S	30.10 E		4.4	0.0	0	528
80	1966	4	6	0.79 N	29.86 E	41				570
81	1966	4	7	0.58 N	29.93 E	33	4.8	0.0	1	558
82	1966	4	9	4.00 S	33.00 E		3.5	0.0	0	448
83	1966	4	12	1.20 N	30.07 E	40				560
84	1966	4	13	0.99 N	30.07 E	17	5.5	0.5	1	553
85	1966	4	13	1.16 N	30.26 E	43				539
86	1966	4	13	1.50 N	30.20 E	0				558
87	1966	4	14	0.93 N	29.94 E	33	5.3	0.1	1	565
88	1966	4	15	0.77 N	29.98 E	26	4.9	0.0	1	557
89	1966	4	16	0.76 N	29.86 E	11	5.1	0.0	1	569
90	1966	4	17	1.00 S	32.00 E		3.9	0.0	1	324
91	1966	4	17	0.50 N	30.40 E	0				505
92	1966	4	17	1.00 S	31.00 E		3.7	0.0	0	433

Table 3.1 List of Earthquake Records (3/9)

No.	Date			Epicenter				Depth	Magnitude	I.S.C		
	Year	Month	Day	Latitude		Longitude				Int.	cm/sec^2 Acc.	km Distance
93	1966	5	9	1.00	S	32.00	E		3.6	0.0	1	324
94	1966	5	9	1.00	S	31.00	E		3.5	0.0	0	433
95	1966	5	10	1.60	N	31.10	E	0				472
96	1966	5	12	0.00	N	31.00	E		4.2	0.0	1	430
97	1966	5	16	0.61	N	30.13	E	33	5.4	0.4	1	537
98	1966	5	17	0.76	N	29.95	E	35	5.5	0.4	1	560
99	1966	5	18	0.00	N	31.00	E		3.8	0.0	0	430
100	1966	5	29	0.62	N	29.93	E	33	5.2	0.0	1	559
101	1966	6	4	0.90	N	29.90	E	33				569
102	1966	6	14	0.19	S	30.28	E	34				509
103	1966	6	14	1.07	N	30.00	E	33	5.2	0.0	1	563
104	1966	6	17	0.75	N	29.91	E	33	5.3	0.1	1	564
105	1966	6	19	0.68	N	29.96	E	33	5.1	0.0	1	557
106	1966	7	2	0.76	N	30.05	E	12	4.6	0.0	1	549
107	1966	7	6	1.30	N	30.50	E	65				519
108	1966	7	10	3.54	S	35.35	E	0				351
109	1966	7	11	4.00	S	36.00	E		4.1	0.0	1	418
110	1966	7	11	1.00	S	35.00	E		3.7	3.0	8	68
111	1966	7	11	3.60	S	35.60	E		3.7	0.0	0	363
112	1966	7	11	3.90	S	35.40	E		4.0	0.0	1	391
113	1966	7	14	5.00	S	35.00	E		3.6	0.0	0	508
114	1966	7	14	0.60	N	29.90	E	33	5.1	0.0	1	561
115	1966	7	14	4.00	S	35.00	E		3.5	0.0	0	398
116	1966	7	14	5.00	S	35.00	E		3.1	0.0	0	508
117	1966	7	15	4.00	S	35.00	E		3.7	0.0	0	398
118	1966	7	15	4.00	S	36.00	E		3.7	0.0	0	418
119	1966	7	21	3.90	S	35.53	E	33				394
120	1966	7	22	0.00	N	31.00	E		3.8	0.0	0	430
121	1966	7	23	4.00	S	36.00	E		3.6	0.0	0	418
122	1966	7	24	3.00	S	36.00	E		3.4	0.0	0	314
123	1966	7	30	0.90	N	30.40	E	0				515
124	1966	7	31	0.67	N	30.02	E	6	5.0	0.0	1	550
125	1966	8	1	0.67	N	30.00	E	38				552
126	1966	8	1	1.00	N	30.03	E	0				558
127	1966	8	15	4.00	S	34.50	E		4.1	0.0	1	400
128	1966	9	2	1.03	N	30.18	E	20				543
129	1966	9	2	0.60	N	31.60	E		4.0	0.0	1	378
130	1966	9	8	3.30	S	35.40	E		3.9	0.0	1	326
131	1966	9	18	4.08	S	33.63	E	33				428
132	1966	9	23	5.00	S	33.00	E		3.7	0.0	0	548
133	1966	9	24	0.70	N	36.20	E	0				193
134	1966	9	24	1.00	N	30.00	E		3.8	0.0	0	561
135	1966	9	26	0.50	N	36.50	E		4.6	1.5	3	209
136	1966	9	26	0.50	N	30.20	E	0				527
137	1966	10	1	0.40	S	31.70	E		3.6	0.0	0	350
138	1966	10	2	5.30	S	35.80	E		3.8	0.0	0	551

Table 3.1 List of Earthquake Records (4/9)

No.	Date			Epicenter		Depth	Magnitude	I.S.C		
	Year	Month	Day	Latitude	Longitude			Int.	cm/sec^2 Acc.	km Distance
139	1966	10	5	0.02 N	29.94 E	28	5.3	0.2	1	548
140	1966	10	9	5.30 S	30.90 E		3.5	0.0	0	697
141	1966	10	10	0.20 N	32.40 E		3.8	0.0	1	280
142	1966	10	18	4.00 S	31.00 E		4.0	0.0	0	584
143	1966	10	26	0.10 N	30.80 E		4.0	0.0	0	454
144	1966	10	30	1.60 S	33.00 E		3.8	0.0	1	245
145	1966	10	30	3.62 S	29.97 E	33	5.2	0.0	1	648
146	1966	11	9	3.50 S	30.40 E		3.6	0.0	0	601
147	1966	11	12	4.00 S	34.00 E		3.8	0.0	0	409
148	1966	11	14	5.08 S	35.80 E	0				528
149	1966	11	17	0.50 N	29.90 E	33				559
150	1966	11	20	4.50 S	35.40 E		4.0	0.0	0	457
151	1966	11	23	3.80 N	31.30 E	0				609
152	1966	11	25	0.80 N	30.02 E	33	4.6	0.0	1	553
153	1966	12	5	1.00 N	30.00 E		3.9	0.0	0	561
154	1966	12	10	5.00 S	36.00 E		3.9	0.0	0	524
155	1966	12	14	2.00 N	31.00 E		4.1	0.0	0	503
156	1966	12	29	1.30 N	29.90 E	0				582
157	1967	1	12	5 .00 S	36.00 E		4.0	0.0	0	524
158	1967	1	12	2.10 N	31.21 E	18				490
159	1967	1	17	4.00 S	36.00 E		3.7	0.0	0	418
160	1967	2	7	0.70 S	30.60 E	0				474
161	1967	2	14	0.20 N	30.36 E	0				504
162	1967	2	16	5.00 S	36.00 E		4.1	0.0	0	524
163	1967	2	25	5.00 S	35.00 E		3.9	0.0	0	508
164	1967	3	10	0.63 N	30.19 E	43				530
165	1967	4	6	1.00 N	31.00 E		3.9	0.0	0	455
166	1967	4	9	3.00 S	32.50 E		3.7	0.0	0	388
167	1967	4	16	4.70 S	34.70 E		4.0	0.0	0	475
168	1967	4	16	3.00 S	36.00 E		3.8	0.0	1	314
169	1967	5	8	4.10 N	35.40 E	0				501
170	1967	5	23	4.20 S	37.00 E		3.6	0.0	0	483
171	1967	5	28	1.86 N	31.39 E	51	5.1	0.3	1	459
172	1967	6	8	0.10 S	30.80 E		4.0	0.0	0	452
173	1967	6	19	0.64 N	30.15 E	34	4.7	0.0	1	535
174	1967	6	28	3.80 S	36.50 E		4.7	0.0	1	418
175	1967	7	4	3.00 S	37.00 E		4.3	0.0	1	374
176	1967	7	8	3.00 S	36.00 E		4.2	0.0	1	314
177	1967	7	13	5.36 S	35.17 E	33				549
178	1967	9	9	4.00 N	32.30 E	33	4.7	0.0	1	563
179	1967	9	15	3.99 S	35.74 E	0				409
180	1967	10	14	3.32 S	38.19 E	33	5.1	0.1	1	492
181	1967	10	19	5.28 S	34.90 E	33				539
182	1967	10	30	1.80 N	31.80 E	107				417
183	1967	10	30	2.60 N	31.60 E	128				490
184	1967	10	31	1.99 N	31.21 E	33	5.2	0.3	1	483

Table 3.1 List of Earthquake Records (5/9)

No.	Date			Epicenter				Depth	Magnitude	I.S.C		
	Year	Month	Day	Latitude		Longitude				Int.	cm/sec^2 Acc.	km Distance
185	1967	11	2	1.70	N	30.40	E	0	4.3	0.0	0	546
186	1967	11	11	2.02	N	31.48	E	33	5.3	0.6	2	460
187	1967	11	13	1.90	N	31.61	E	33	5.1	0.4	1	441
188	1967	11	29	2.00	N	31.20	E	0	4.6	0.0	1	485
189	1967	11	29	1.90	N	31.80	E	0				424
190	1967	12	2	4.00	S	36.00	E		3.9	0.0	0	418
191	1967	12	28	1.00	S	31.40	E		3.6	0.0	0	389
192	1967	12	29	0.20	S	32.20	E	0	4.2	0.1	1	295
193	1967	12	29	3.00	N	31.40	E	0	4.4	0.0	0	537
194	1967	12	29	2.80	N	31.20	E	0	4.4	0.0	0	538
195	1967	12	29	1.30	N	34.00	E		4.1	0.8	2	210
196	1967	12	29	1.30	N	34.00	E		4.0	0.6	2	210
197	1967	12	30	2.10	S	29.95	E	0	4.7	0.0	1	576
198	1968	1	17	5.20	S	31.10	E		3.4	0.0	0	674
199	1968	2	17	5.20	S	35.70	E	33				538
200	1968	2	17	5.09	S	35.72	E	0				527
201	1968	2	17	5.10	S	35.80	E	33				530
202	1968	2	17	5.10	S	35.80	E	33				530
203	1968	3	13	5.00	S	38.00	E		3.4	0.0	0	617
204	1968	3	14	1.00	S	33.80	E		3.9	1.6	3	134
205	1968	3	14	1.00	S	33.80	E		4.1	1.9	4	134
206	1968	3	16	0.61	S	34.40	E	0				55
207	1968	3	18	0.50	S	34.00	E		3.9	2.5	6	95
208	1968	3	20	0.61	S	34.42	E	13				53
209	1968	3	21	0.58	S	34.38	E	41				56
210	1968	3	21	0.50	S	34.20	E		4.0	3.3	10	73
211	1968	3	21	0.50	S	34.30	E		4.0	3.7	13	62
212	1968	3	21	0.60	S	34.37	E	0				58
213	1968	3	21	0.30	S	34.44	E	0				47
214	1968	3	31	4.67	S	34.96	E	33				472
215	1968	4	1	0.66	S	34.41	E	0				57
216	1968	4	21	4.00	S	33.00	E		3.6	0.0	0	448
217	1968	5	6	4.30	S	30.40	E		3.6	0.0	0	656
218	1968	5	10	0.69	S	34.40	E	18				59
219	1968	5	20	3.17	S	37.10	E	33				395
220	1968	6	1	3.30	S	33.50	E		4.0	0.0	1	354
221	1968	6	6	3.80	S	36.60	E		3.8	0.0	0	423
222	1968	6	7	4.00	S	35.00	E	0				398
223	1968	6	10	3.80	S	35.30	E	0				379
224	1968	6	13	2.21	N	33.95	E	66				305
225	1968	6	23	4.57	S	30.35	E	0				680
226	1968	6	24	0.50	S	29.90	E	0				551
227	1968	6	24	0.36	S	29.89	E	33	5.0	0.0	1	552
228	1968	7	2	0.00	N	30.00	E		4.4	0.0	0	541
229	1968	7	3	4.81	S	34.98	E	33				487
230	1968	7	6	5.04	S	35.70	E	0				521

Table 3.1 List of Earthquake Records (6/9)

No.	Date			Epicenter				Depth	Magnitude	I.S.C		
	Year	Month	Day	Latitude		Longitude				Int.	cm/sec^2 Acc.	km Distance
231	1968	7	6	1.26	S	33.35	E	30				192
232	1968	8	7	4.28	S	35.07	E	0				429
233	1968	9	7	4.00	S	33.00	E		3.8	0.0	0	448
234	1968	9	7	4.63	S	35.66	E	0				476
235	1968	9	21	1.00	N	30.30	E	0				529
236	1968	11	6	3.30	N	35.50	E	0				415
237	1968	11	13	1.89	N	31.52	E	23				448
238	1968	11	26	0.80	N	30.02	E	0				553
239	1969	1	4	5.20	N	34.20	E		3.9	0.0		535
240	1969	1	25	3.81	S	35.63	E	34				386
241	1969	1	25	3.62	S	35.80	E	33				371
242	1969	2	26	5.22	S	33.89	E	0				543
243	1969	3	13	0.60	N	30.60	E		4.0	0.0	0	485
244	1969	3	14	0.80	S	29.90	E	33				552
245	1969	4	5	4.50	N	31.60	E	29				651
246	1969	4	14	4.26	S	31.10	E	0				596
247	1969	4	14	4.95	S	30.40	E	0				705
248	1969	4	14	4.86	S	30.20	E	33				714
249	1969	4	18	3.20	S	36.44	E	33				356
250	1969	4	22	1.96	N	31.49	E	32				456
251	1969	4	29	0.76	S	30.91	E	27	4.6	0.0	1	440
252	1969	4	30	4.48	S	35.24	E	0				453
253	1969	5	10	3.84	S	35.69	E	33				391
254	1969	5	23	4.50	S	31.00	E		3.5	0.0	0	623
255	1969	5	25	3.90	S	36.00	E	33				407
256	1969	5	30	4.30	S	36.10	E	0				453
257	1969	6	20	3.90	S	35.70	E	0				398
258	1969	7	15	3.00	S	33.60	E		4.0	0.0	1	319
259	1969	7	15	3.62	N	31.44	E	15				584
260	1969	8	16	4.50	S	33.00	E		3.3	0.0	0	497
261	1969	8	23	1.10	N	30.00	E	0	4.2	0.0	0	564
262	1969	8	26	0.40	N	30.20	E	0				525
263	1969	9	5	0.30	S	30.80	E	0				450
264	1969	12	3	4.14	S	35.40	E	0				418
265	1969	12	14	1.25	S	34.02	E	0				132
266	1969	12	26	3.28	S	36.00	E	33				343
267	1969	12	29	4.90	S	38.40	E	0				634
268	1970	3	16	4.64	S	38.40	E	0				612
269	1970	6	6	4.60	S	32.10	E		3.5	0.0	0	555
270	1970	7	1	3.70	S	35.60	E	0				374
271	1970	12	11	5.30	S	30.00	E		3.3	0.0	0	763
272	1971	1	3	1.85	N	30.65	E	38	4.0	0.0	0	529
273	1971	1	4	3.88	N	32.63	E	0	4.1	0.0	0	534
274	1971	1	5	4.70	S	36.79	E	0	4.0	0.0	0	522
275	1971	1	19	4.29	S	30.29	E	0	4.0	0.0	0	664
276	1971	1	20	3.44	S	35.18	E	0	3.9	0.0	1	339

Table 3.1 List of Earthquake Records (7/9)

No.	Date			Epicenter		Depth	Magnitude	I.S.C		
	Year	Month	Day	Latitude	Longitude			Int.	cm/sec^2 Acc.	km Distance
277	1971	3	6	3.64 S	35.49 E	0	4.1	0.0	1	366
278	1971	3	13	5.30 S	30.00 E	0	3.7	0.0	0	763
279	1971	4	18	0.28 N	30.03 E	0	4.6	0.0	1	541
280	1971	4	18	0.20 N	30.05 E	32	4.8	0.0	1	537
281	1971	4	21	0.19 N	29.86 E	0	4.3	0.0	0	558
282	1971	5	19	4.14 S	30.24 E	0	3.8	0.0	0	658
283	1971	9	7	4.30 N	33.60 E	0				537
284	1972	1	8	0.58 N	30.08 E	33	4.3	0.0	0	541
285	1972	1	12	4.00 S	33.30 E	0	4.2	0.0	1	433
286	1972	2	13	4.50 S	34.14 E	33	4.8	0.0	1	460
287	1972	2	17	4.17 S	34.41 E	0	4.6	0.0	1	420
288	1972	4	15	5.10 S	33.00 E	0	3.8	0.0	0	558
289	1972	4	22	5.10 S	30.20 E	0	3.8	0.0	0	732
290	1972	5	4	4.10 S	35.51 E	0	5.0	0.4	1	416
291	1972	8	25	3.44 S	35.98 E	0	4.2	0.0	1	358
292	1972	9	10	0.29 S	25.11 E	0	4.6	6.3	78	32
293	1972	10	30	3.27 S	36.66 E	33	4.6	0.1	1	376
294	1972	10	30	3.57 S	35.81 E	0	4.4	0.0	1	366
295	1972	10	30	2.58 S	36.55 E	0	4.4	0.4	1	307
296	1972	10	30	3.41 S	36.49 E	0	4.6	0.1	1	380
297	1972	11	7	3.50 S	36.41 E	0	4.3	0.0	1	385
298	1972	11	8	3.59 S	35.96 E	0	4.5	0.0	1	375
299	1973	3	29	3.30 S	38.86 E	0	4.5	0.0	1	550
300	1973	4	11	4.93 S	36.96 E	0	4.3	0.0	0	516
301	1973	4	22	4.14 N	31.31 E	0	3.9	0.0	0	638
302	1973	7	7	3.04 S	35.56 E	33	4.5	0.5	1	303
303	1973	7	28	5.14 S	35.13 E	0	3.9	0.0	0	526
304	1973	8	5	5.30 S	30.00 E	0	3.7	0.0	0	763
305	1973	8	8	4.85 S	29.90 E	0	4.0	0.0	0	737
306	1973	9	11	4.85 S	34.44 E	0	3.7	0.0	0	494
307	1973	11	15	4.90 S	34.90 E	0	4.2	0.0	0	497
308	1973	11	19	4.28 N	31.32 E	0	5.4	0.0	1	649
309	1973	12	29	3.31 S	35.48 E	0	4.0	0.0	1	330
310	1974	1	10	0.49 N	29.90 E	0	4.7	0.0	1	559
311	1974	1	14	4.50 S	34.30 E	0	3.8	0.0	0	457
312	1974	1	17	0.17 S	30.09 E	0	4.5	0.0	1	529
313	1974	2	2	5.10 S	33.69 E	0	4.8	0.0	1	535
314	1974	4	25	1.10 N	30.04 E	11	4.6	0.0	1	559
315	1974	4	25	1.27 N	30.10 E	0	4.5	0.0	0	559
316	1974	7	13	3.30 S	32.30 E	0	4.4	0.0	1	428
317	1974	9	19	3.61 S	34.72 E	0	4.2	0.0	1	356
318	1974	10	26	3.94 S	33.30 E	0	4.8	0.1	1	427
319	1974	11	9	4.89 S	32.08 E	0	4.3	0.0	0	584
320	1974	12	6	3.00 S	33.00 E	0	4.5	0.1	1	353
321	1975	3	5	4.34 N	31.09 E	0	5.3	0.0	1	670
322	1975	3	23	5.00 S	30.17 E	0	4.3	0.0	0	727

Table 3.1 List of Earthquake Records (8/9)

No.	Date			Epicenter				Depth	Magnitude	I.S.C		
	Year	Month	Day	Latitude		Longitude				Int.	cm/sec^2 Acc.	km Distance
323	1975	3	24	4.97	S	30.73	E	0	4.2	0.0	0	681
324	1975	3	25	4.91	S	30.84	E	0	4.3	0.0	0	668
325	1975	3	26	5.33	S	30.13	E	28	4.8	0.0	0	756
326	1975	3	26	3.35	S	32.33	E	0	4.2	0.0	1	430
327	1975	3	26	4.23	S	33.39	E	0	4.4	0.0	1	453
328	1975	3	28	4.76	S	30.10	E	0	4.2	0.0	0	715
329	1975	5	9	3.00	S	30.00	E	0	4.0	0.0	0	611
330	1975	5	23	5.04	S	30.74	E	0	4.5	0.0	0	687
331	1975	7	28	4.12	S	35.23	E	0	4.7	0.0	1	414
332	1975	8	2	2.80	S	37.50	E	0	5.0	0.5	1	397
333	1975	8	5	2.35	S	38.76	E	0	4.6	0.0	1	486
334	1975	8	6	4.35	S	35.75	E	32	5.4	0.8	2	448
335	1975	8	26	4.51	S	30.90	E	0	3.8	0.0	0	631
336	1975	9	26	2.64	S	38.28	E	0	4.6	0.0	1	455
337	1975	10	22	3.91	S	35.62	E	0	4.4	0.0	1	398
338	1975	11	29	2.39	S	36.15	E	0	4.1	0.2	1	264
339	1975	11	29	2.74	S	37.01	E	0	4.7	0.4	1	353
340	1975	12	23	2.71	S	37.86	E	0	4.6	0.0	1	421
341	1975	12	26	3.28	S	30.06	E	0	4.5	0.0	0	620
342	1975	12	26	3.41	S	36.47	E	0	4.4	0.0	1	379
343	1975	12	29	3.61	S	37.15	E	0	4.6	0.0	1	438
344	1976	1	9	2.44	S	38.41	E	0	4.4	0.0	1	456
345	1976	1	16	3.10	S	37.20	E	0	4.2	0.0	1	396
346	1976	1	16	2.11	N	31.44	E	0	5.0	0.1	1	470
347	1976	1	19	2.94	S	37.46	E	26	4.9	0.3	1	404
348	1976	1	21	2.81	S	37.34	E	0	4.5	0.0	1	385
349	1976	2	5	2.78	S	36.97	E	41	4.8	0.5	1	354
350	1976	2	9	2.85	S	37.38	E	0	4.5	0.0	1	391
351	1976	6	8	3.30	S	36.30	E	0	4.4	0.0	1	359
352	1976	7	31	0.60	N	30.40	E	0	4.6	0.0	1	507
353	1976	11	29	2.66	S	36.93	E	0	4.2	0.0	1	341
354	1977	3	19	3.00	S	37.00	E	0	4.1	0.0	1	374
355	1977	3	25	2.80	S	37.06	E	0	4.3	0.0	1	362
356	1977	6	27	4.25	S	36.09	E	0	4.1	0.0	0	447
357	1977	10	7	0.90	N	30.60	E	0	4.7	0.0	1	494
358	1977	12	15	4.79	S	34.91	E	0	5.2	0.3	1	486
359	1977	12	28	2.02	N	31.19	E	20	4.9	0.0	1	487
360	1978	1	4	4.91	S	34.84	E	0	4.5	0.0	1	498
361	1978	2	16	5.00	S	34.40	E	0	4.5	0.0	1	512
362	1978	2	20	3.73	S	33.63	E	0	4.8	0.3	1	392
363	1978	3	2	5.30	S	30.20	E	0	4.0	0.0	0	748
364	1978	4	5	1.71	S	37.15	E	25	4.3	0.3	1	294
365	1978	4	10	3.59	S	34.53	E	0	4.6	0.2	1	355
366	1978	5	4	4.96	S	30.61	E	0	3.7	0.0	0	690
367	1978	5	23	2.96	N	36.22	E	7	3.9	0.0	0	402
368	1978	7	13	0.22	N	30.44	E	0	4.6	0.0	1	496

Table 3.1 List of Earthquake Records (9/9)

No.	Date			Epicenter				Depth	Magnitude	I.S.C		
	Year	Month	Day	Latitude		Longitude				Int.	cm/sec^2 Acc.	km Distance
369	1978	7	26	4.86	S	38.44	E	0	4.1	0.0	0	434
370	1978	11	3	5.14	S	30.71	E	0	3.5	0.0	0	696
371	1978	11	3	4.83	S	31.15	E	0	4.3	0.0	0	639
372	1978	11	26	5.25	S	36.37	E	0	4.2	0.0	0	563
373	1978	12	7	4.54	S	30.29	E	0	4.4	0.0	0	683
374	1978	12	8	4.70	S	30.30	E	0	3.8	0.0	0	693
375	1978	12	8	4.60	S	30.40	E	0	4.1	0.0	0	678
376	1978	12	8	4.40	S	30.40	E	0	4.4	0.0	0	663
377	1979	2	26	1.84	N	30.93	E	6	4.1	0.0	0	501
378	1979	3	9	1.29	N	30.51	E	33	4.8	0.0	1	518
379	1979	3	20	2.00	S	36.00	E	0	4.4	0.2	1	314
380	1979	4	15	1.10	N	30.30	E	0	4.7	0.0	1	532
381	1979	6	26	4.14	N	30.47	E	0	5.2	0.0	1	699
382	1979	7	2	4.29	S	32.69	E	0	4.4	0.0	1	492
383	1979	11	4	4.18	S	34.53	E	19	3.7	0.0	0	420
384	1979	12	4	1.74	N	31.28	E	57	5.0	0.1	1	462
385	1980	2	29	4.96	S	30.07	E	0	4.7	0.0	0	731
386	1980	3	24	4.70	S	39.00	E	0	4.1	0.0	0	662
387	1980	4	5	3.70	S	33.60	E	0	4.1	0.0	1	390
388	1980	5	19	3.78	S	35.42	E	0	3.9	0.0	1	379
389	1980	5	20	4.16	S	34.68	E	33	3.6	0.0	0	416
390	1980	6	9	0.74	N	30.14	E	0	4.4	0.0	0	539
391	1980	6	13	2.00	S	31.00	E	0	4.4	0.0	1	463
392	1980	9	23	1.75	N	30.67	E	0	3.3	0.0	0	522
393	1980	9	26	1.02	N	29.94	E	33	2.9	0.0	0	568
394	1980	10	29	3.85	S	36.00	E	33	4.4	0.0	1	403
395	1980	11	20	5.27	S	35.43	E	0	3.5	0.0	0	543
396	1980	12	4	2.13	S	39.75	E	0	4.3	0.0	0	578
397	1980	12	11	1.00	S	30.20	E	0	4.2	0.0	0	521
398	1980	12	12	0.39	N	30.17	E	0	4.7	0.0	1	528
399	1981	2	7	1.84	N	30.86	E	0	4.3	0.0	0	508
400	1981	3	4	1.37	N	30.54	E	24	4.8	0.0	1	518
401	1981	10	19	2.10	S	31.77	E	0	4.1	0.0	1	391
402	1981	12	19	4.90	S	30.02	E	0	3.7	0.0	0	731
403	1982	7	24	1.22	N	30.10	E	10	3.7	0.0	0	557
404	1982	8	14	4.76	S	34.56	E	10	2.2	0.0	0	483

Table 3.2 Estimation of Ground Acceleration at Sondu/Miuri Damsite

	1928. 1. 6 Magnitude 7.0 Distance 209 km		1972. 9. 10 Magnitude 4.6 Distance 32 km	
I.S.C/1	5.1 (MMS)	36 gal	6.3 (MMS)	78 gal
Estiva's formula		20.3 gal		38.2 gal
Kawasumi's formula	2.63 (JMA)	93 gal	1.67 (JMA)	3.1 gal
Seismic Zoning Map of KENYA /2 (Figure 3.2)	VI (MMS) Middle third of (JMA)		21.0 - 44.0 gal IV (JMA) ≑ 50 gal	 25.0 - 80.0 gal
World Map of Natural Hazards/3	VI and VII (MMS) Latter third of IV (JMA)		VI (MMS) VII(MMS) IV (JMA) ≑ 50 - 60 gal	21.0 - 44.0 gal 44.0 - 94.0 gal 25.0 - 80.0 gal

/1 International Seismological Centre

/2 Seismic Zoning Map of Kenya
Showing Maximum Observed Intensities (1892 - 1969)
I.S. LOUPEKINE, JULY 1971

/3 World Map of Natural Hazards
Maximum Intensity (Mercalli Scale) once in 50 years,
for average ground conditions

Table 3.3 Earthquake Intensity and Frequency

Invensity (i)	Frequency in 71 years	Frequency in 100 years	Cumulative number for 100 years (Nc)
0.4	264	371	422
0.5 - 1.4	16	23	50
1.5 - 2.4	7	10	27
2.5 - 3.4	7	10	17
3.5 - 4.4	2	3	7
4.5 - 5.4	1	2	4
5.5 - 6.4	1	2	2
Total	298	421	

Table 4.1 Quality Classification of Rock

Classification	Characteristics
A	Rock-forming minerals[1] are fresh and not weathered or altered. Joints and cracks are very closely adhered with no weathering along their planes. A clear sound is emitted when hammered.
B	Rock-forming minerals are weathered slightly or partially altered, the rock being hard. Joints and cracks are closely adhered. A clear sound is emitted when hammered.
CH	Rock-forming minerals are weathered but the rock is fairly hard. The bond between rock blocks is slightly reduced and each block is apt to be exfoliated along joints and cracks by strong hammering. Joints and cracks sometimes contain clay and other material which may be coloured by limonite. A slightly dull sound is emitted when hammered.
CM	Rock-forming minerals are weathered and the rock is slightly soft. Exfoliation of the rock occurs along joints and cracks by normal hammering. Joints and cracks sometimes contain clay and other material. A somewhat dull sound is emitted when hammered.
CL	Rock-forming minerals are weathered and the rock is soft. Exfoliation of the rock occurs along joints and cracks by light hammering. Joints and cracks contain clay. A dull sound is emitted when hammered.
D	Rock-forming minerals are weathered, and rock is very soft. There is virtually no bond between rock blocks, and collapse occurs at the slightest hammering. Joints and cracks contain clay. A very dull sound is emitted when hammered.

(1): Except quartz

Table 4.2 Boring Work Quantity

Boring Number	Location	Elevation (M)	Boring Depth(M)	Permeability	Remarks		
BD - 1	A-1270	1447.14	15	3	90°	Damsite	(Right Bank)
- 2	A- 930	1430.96	30	4	"	"	"
- 3	A- 780	1397.86	50	8	"	"	"
- 4	A- 590	1352.24	70	13	50°	"	"
- 5	A- 520	1350.44	70	13	50°	"	(Left Bank)
- 6	A- 350	1369.22	35	6	90°	"	"
- 7	A- 190	1409.74	45	8	"	"	"
- 8	A- 70	1450.40	30	4	"	"	"
- 9	B- 50	1392.02	45	4	"	"	(Right Bank)
-10	Upstream	1371.00	20	3	"	"	"
-11	C- 100	1370.75	30	5	"	"	(Left Bank)
-12	C- 610	1362.02	30	5	"	"	"
-13	Upstream	1370	30	5	"	"	(Right Bank)
BS - 1	A-1100	1429.91	30	3	"	"	(Spillway)
- 2	E- 500	1384.12	20	3	"	"	"
Sub-total			550.00 m	87 times			
BT - 1	N- 300	1389.61	20		90°	Tunnel Line	
- 2	N- 770	1443.28	70		"	"	
- 3	L-1620	1431.46	70		"	"	
- 4	M- 305	1431.80	70		"	Surge Tank	
BP - 1	M- 700	1275.10	30		"	Power Station	
- 2	M-1090	1243.64	50		"	"	
- 3	M-1260	1229.56	30		"	"	
Sub-total			340.00 m				
BQ - 1	F- 200	1481.30	40		90°	Quarry Site	
- 2	F- 900	1442.97	40		"	"	
Sub-total			80.00 m				
Total	24 holes		970.00 m	87 times			

Table 4.3 Records of Water Pressure Tests (1/4)

Date	Depth		Section Length	Hole Radius	Supplied Water Pressure		Static Head in Hole	Pressure Gauge Height	Total Head $H_p+H_s+H_g$	Water Leakage		Lugeon Unit
	m–	m	L cm	r cm	Pressure P kg/cm^2	Head Hp cm	Hs cm	Hg cm	H cm	Q' /min	Q cm^3/min	$Lu=Q'/L\cdot H\times 10^6$
	BD - 1											
16/10	3.50 -	8.00	450	8.6	1	1,000	575	300	1,875	62	62,000	73.5
17/10	8.00 -	13.00	500	8.6	10	10,000	1,050	275	11,325	63.6	63,600	11.2
17/10	13.00 -	15.41	241	7.6	10	10,000	1,420	241	11,661	9.5	9,500	3.4
	BD - 2											
6/10	9.53 -	13.00	347	8.6	10	10,000	1,126	165	11,291	27.4	27,400	7.0
6/10	12.00 -	17.10	510	8.6	10	10,000	1,455	165	11,620	32.1	32,100	5.4
7/10	17.00 -	22.30	530	7.6	10	10,000	1,965	65	12,030	0	0	0
8/10	22.00 -	30.00	800	6.6	10	10,000	2,600	100	12,700	18.3	18,300	1.8
	BD - 3											
20/9	6.17 -	11.10	493	8.6	4	4,000	863	95	4,958	40	40,000	16.4
24/9	11.00 -	16.30	530	8.6	10	10,000	1,365	165	11,530	79.6	79,600	13.0
26/9	16.30 -	21.30	500	7.6	10	10,000	1,880	165	12,045	17	17,000	2.8
28/9	21.30 -	26.20	490	7.6	10	10,000	2,865	165	13,030	0	0	0
28/9	26.20 -	31.30	510	7.6	10	10,000	2,875	165	13,040	1.8	1,800	0.3
29/9	31.00 -	36.00	500	7.6	10	10,000	3,350	350	13,700	0	0	0
29/9	36.00 -	40.70	470	7.6	10	10,000	3,835	60	13,895	0	0	0
1/10	40.60 -	50.00	940	7.6	10	10,000	4,530	165	14,695	1.0	1,000	0.1
	BD - 4											
14/9	3.60 -	7.60	400	10.1	10	10,000	428	80	10,508	85.1	85,100	20.2
14/9	7.60 -	12.50	490	10.1	10	10,000	769	80	10,845	44.5	44,500	8.4
15/9	12.50 -	18.00	550	8.6	10	10,000	1,168	80	11,248	0.1	100	0.02
16/9	18.00 -	23.70	570	7.6	10	10,000	1,597	80	11,677	0.2	200	0.03
16/9	23.60 -	28.30	470	7.6	10	10,000	1,987	80	12,067	0.1	100	0.02
17/9	28.30 -	34.20	590	7.6	10	10,000	2,393	130	12,523	0.6	600	0.1
18/9	34.20 -	39.90	570	7.6	10	10,000	2,838	80	12,918	0	0	0
19/9	39.90 -	46.30	640	7.6	10	10,000	3,301	80	13,381	0	0	0
20/9	46.30 -	51.30	500	6.6	10	10,000	3,738	80	13,818	0	0	0
24/9	51.20 -	56.50	530	6.6	10	10,000	4,124	80	14,204	0	0	0
25/9	56.50 -	60.80	430	6.6	10	10,000	4,492	80	14,572	1.4	1,400	0.2
26/9	60.80 -	65.00	420	6.6	10	10,000	4,818	80	14,898	2.5	2,500	0.4
"	65.00 -	70.00	500	6.6	10	10,000	5,170	80	15,250	0	0	0

Table 4.3 Records of Water Pressure Tests (2/4)

Date	Depth	Section Length	Hole Radius	Supplied Water Pressure		Static Head in Hole	Pressure Gauge Height	Total Head Hp+Hs+Hg	Water Leakage		Lugeon Unit
	m– m	L cm	r cm	Pressure P kg/cm^2	Head Hp cm	Hs cm	Hg cm	H cm	Q' /min	Q cm^3/min	Lu=Q'/L·Hx10^6
	BD – 5										
14/8	3.45 – 8.28	483	10.1	10	10,000	449	165	10,614	1.5	1,500	0.3
15/8	8.00 – 13.00	500	10.1	10	10,000	804	165	10,969	50.1	50,100	9.1
16/8	11.60 – 18.00	640	10.1	10	10,000	1,133	165	11,298	40.4	40,400	5.6
17/8	19.00 – 24.00	500	8.6	10	10,000	1,646	165	11,811	0.9	900	0.2
17/8	24.00 – 29.00	500	8.6	10	10,000	2,029	165	12,194	0	0	0
18/8	29.00 – 34.00	500	8.6	10	10,000	2,412	165	12,577	0	0	0
19/8	34.00 – 39.00	500	8.6	10	10,000	2,795	165	12,960	6.5	6,500	1.0
20/8	39.00 – 44.00	500	8.6	10	10,000	3,178	165	13,343	5.1	5,100	0.8
20/8	44.00 – 49.00	500	8.6	10	10,000	3,561	165	13,726	0.5	500	0.1
21/8	49.00 – 54.00	500	8.6	10	10,000	3,944	165	14,109	0	0	0
22/8	54.00 – 59.00	500	8.6	10	10,000	4,327	165	14,492	0	0	0
24/8	59.00 – 64.00	500	7.6	10	10,000	4,710	165	14,875	0.9	900	0.1
25/8	64.00 – 70.20	620	7.6	10	10,000	5,139	165	15,304	0	0	0
	BD – 6										
1/9	3.82 – 8.90	508	10.1	10	10,000	636	25	10,661	77.5	77,500	14.3
"	9.60 – 13.90	430	8.6	10	10,000	1,175	362	11,537	46.8	46,800	9.4
"	13.90 – 18.90	500	7.6	10	10,000	1,640	345	11,985	2.9	2,900	0.5
"	18.90 – 23.90	500	7.6	4	4,000	2,140	0	6,140	2.0	2,000	0.7
"	23.88 – 28.88	500	7.6	10	10,000	2,638	722	13,360	1.4	1,400	0.2
"	28.88 – 35.10	622	7.6	10	10,000	3,199	362	13,561	11.4	11,400	1.4
	BD – 7										
27/8	5.70 – 10.00	430	10.1	10	10,000	785	100	10,885	31.0	31,000	6.6
28/8	10.90 – 15.00	410	8.6	10	10,000	1,295	165	11,460	41.0	41,000	8.7
29/8	15.00 – 20.00	500	8.6	7	7,000	1,750	165	8,915	51.0	51,000	11.4
30/8	20.00 – 25.00	500	7.6	10	10,000	2,250	165	12,415	48.0	48,000	7.7
31/8	25.00 – 30.00	500	7.6	10	10,000	2,750	165	12,915	55.5	55,500	8.6
1/9	30.00 – 35.00	500	7.6	10	10,000	3,250	165	13,415	53.5	53,500	8.0
3/9	35.00 – 40.00	500	7.6	10	10,000	3,750	165	13,915	31.0	31,000	4.5
4/9	40.00 – 45.00	500	7.6	10	10,000	4,250	165	14,415	3.9	3,900	0.5

Table 4.3 Records of Water Pressure Tests (3/4)

Date	Depth	Section Length	Hole Radius	Supplied Water Pressure: Pressure	Supplied Water Pressure: Head	Static Head in Hole	Pressure Gauge Height	Total Head Hp+Hs+Hg	Water Leakage		Lugeon Unit
	m– m	L cm	r cm	P kg/cm^2	Hp cm	Hs cm	Hg cm	H cm	Q' /min	Q cm^3/min	Lu=Q'/L·Hx10^6
	BD – 8										
16/8	1.80 – 6.61	481	8.6	4	4,000	420	127	4,547	65.0	65,000	29.7
17/8	6.61 – 11.61	500	7.6	10	10,000	911	10	10,921	96.2	96,200	17.6
18/8	11.61 – 16.49	488	7.6	10	10,000	1,405	10	11,415	17.0	17,000	3.1
20/8	16.49 – 22.10	561	7.6	4	4,000	1,929	286	6,215	22.75	22,750	6.5
21/8	22.10 – 26.67	457	7.6	10	10,000	2,438	302	12,740	5.4	5,400	0.9
22/8	26.67 – 30.21	354	7.6	10	10,000	2,844	150	12,994	14.5	14,500	3.2
	BD – 9										
10/10	23.50 – 29.10	560	8.6	10	10,000	2,630	150	12,780	1.2	1,200	0.2
10/10	29.10 – 34.30	520	8.6	10	10,000	3,170	205	13,375	1.5	1,500	0.2
11/10	34.30 – 39.70	540	8.6	10	10,000	3,700	295	13,995	0.9	900	0.1
12/10	39.70 – 45.00	530	8.6	10	10,000	4,235	90	14,325	1.4	1,400	0.2
	BD – 10										
5/10	6.00 – 11.50	550	8.6	10	10,000	875	360	11,235	20.7	20,700	3.3
5/10	11.50 – 15.10	400	8.6	10	10,000	1,310	175	11,485	5.0	5,000	1.1
6/10	15.10 – 20.00	490	8.6	10	10,000	1,755	385	12,140	3.0	3,000	0.5
	BD – 11										
10/9	4.30 – 8.30	400	10.1	10	10,000	630	165	10,795	6.7	6,700	1.6
10/9	8.00 – 13.30	500	8.0	10	10,000	1,080	165	11,245	5.5	5,500	1.0
11/9	13.30 – 18.30	500	8.6	10	10,000	1,330	165	11,495	4.7	4,700	0.8
11/9	18.30 – 23.30	500	8.6	10	10,000	2,080	165	12,245	3.3	3,300	0.5
12/9	23.30 – 30.30	700	8.6	10	10,000	2,680	165	12,845	2.2	2,200	0.2
	BD – 12										
31/8	3.90 – 8.10	420	10.1	10	10,000	600	125	10,725	24.9	24,900	5.5
2/9	10.18 – 14.54	436	8.6	10	10,000	1,236	129	11,365	3.0	3,000	0.6
"	14.54 – 20.54	600	7.6	10	10,000	1,754	325	12,079	1.5	1,500	0.2
"	20.54 – 25.30	476	7.6	10	10,000	2,292	200	12,492	1.1	1,100	0.2
"	25.30 – 30.20	490	7.6	10	10,000	2,275	415	12,690	3.0	3,000	0.5

Table 4.3 Records of Water Pressure Tests (4/4)

Date	Depth	Section Length	Hole Radius	Supplied Water Pressure		Static Head in Hole	Pressure Gauge Height	Total Head Hp+Hs+Hg	Water Leakage		Lugeon Unit
	m– m	L cm	r cm	Pressure P kg/cm^2	Head Hp cm	Hs cm	Hg cm	H cm	Q' /min	Q cm^3/min	Lu=Q'/L·Hx10^6
	BD - 13										
2/9	5.30 - 10.06	476	8.6	10	10,000	768	280	11,048	47.5	47,500	9.0
"	10.06 - 15.10	504	8.6	10	10,000	1,258	350	11,608	1.5	1,500	0.3
"	15.10 - 20.10	500	8.6	10	10,000	1,760	185	11,945	0.5	500	0.1
"	20.10 - 25.10	500	8.6	10	10,000	2,260	185	12,445	0	0	0
"	25.10 - 30.00	490	8.6	10	10,000	2,755	235	12,990	0	0	0
	BS - 1										
12/10	14.00 - 21.29	729	7.6	10	10,000	1,764	109	11,873	22.8	22,800	2.6
"	21.29 - 26.43	514	7.6	10	10,000	2,386	100	12,486	2.8	2,800	0.4
"	26.29 - 30.00	371	7.6	10	10,000	2,814	100	12,914	1.3	1,300	0.3
	BS - 2										
19/10	5.48 - 10.48	500	7.6	10	10,000	798	165	10,963	48.5	48,500	8.8
21/10	10.48 - 15.75	527	7.6	10	10,000	1,311	165	11,476	0.4	400	0.1
22/10	15.75 - 20.00	452	7.6	10	10,000	1,774	165	11,939	0	0	0

Table 4.4 List of Seismic Refraction Profile

Profile No.	Length (m)	Locations
A	1,355	Lower storage damsite
B	610	Diversion tunnel
C	800	Upper intake damsite
E	800	Spillway
F	1,000	Quarry site
H	500	"
I	500	"
N	1,000	Intake of waterway
L	3,610	Waterway
M	1,380	Surge tank and Penstock
P	230	Power station
Q	300	Waterway
Total	12,085	

Table 4.5 List of Instruments and Materials

Item	Name	Description	Quantity
Oscillograph	SIE, R-6AB	24 CH, 125 Hz	1 No.
Amplifier	MR-4600, ADII-MDF	24 CH, 100 db	1 No.
Blaster	GB-106A	microphones inclusive	3 Nos.
Geophones	Marsh type	14 Hz	24 Nos.
Takeout cable	GT-T-10-12	24 CH	2 rolls
Linagraph	KODAK, Type 1895	SPEC 2	10 rolls
Geligunite			100 kg
Detonator			500 pcs.

Table 4.6 Relationship between Seimic Wave Speed and its Corresponding Geology

Speed Layer	Seismic Wave Velocity	Assumed Geology
1ST velocity layer	0.3 to 0.6 km/sec.	Top soil and talus
2ND velocity layer	1.0 to 1.2 km/sec.	Talus or severely weathered rock
3RD velocity layer	1.7 to 1.8 km/sec.	Highly weathered rock
4TH velocity layer	2.6 to 2.8 km/sec.	Slightly weathered rock
5TH velocity layer	3.7 to 3.9 km/sec.	Very slightly weathered rock
6TH velocity layer	5.6 to 6.0 km/sec.	Fresh rock