# FIGURES

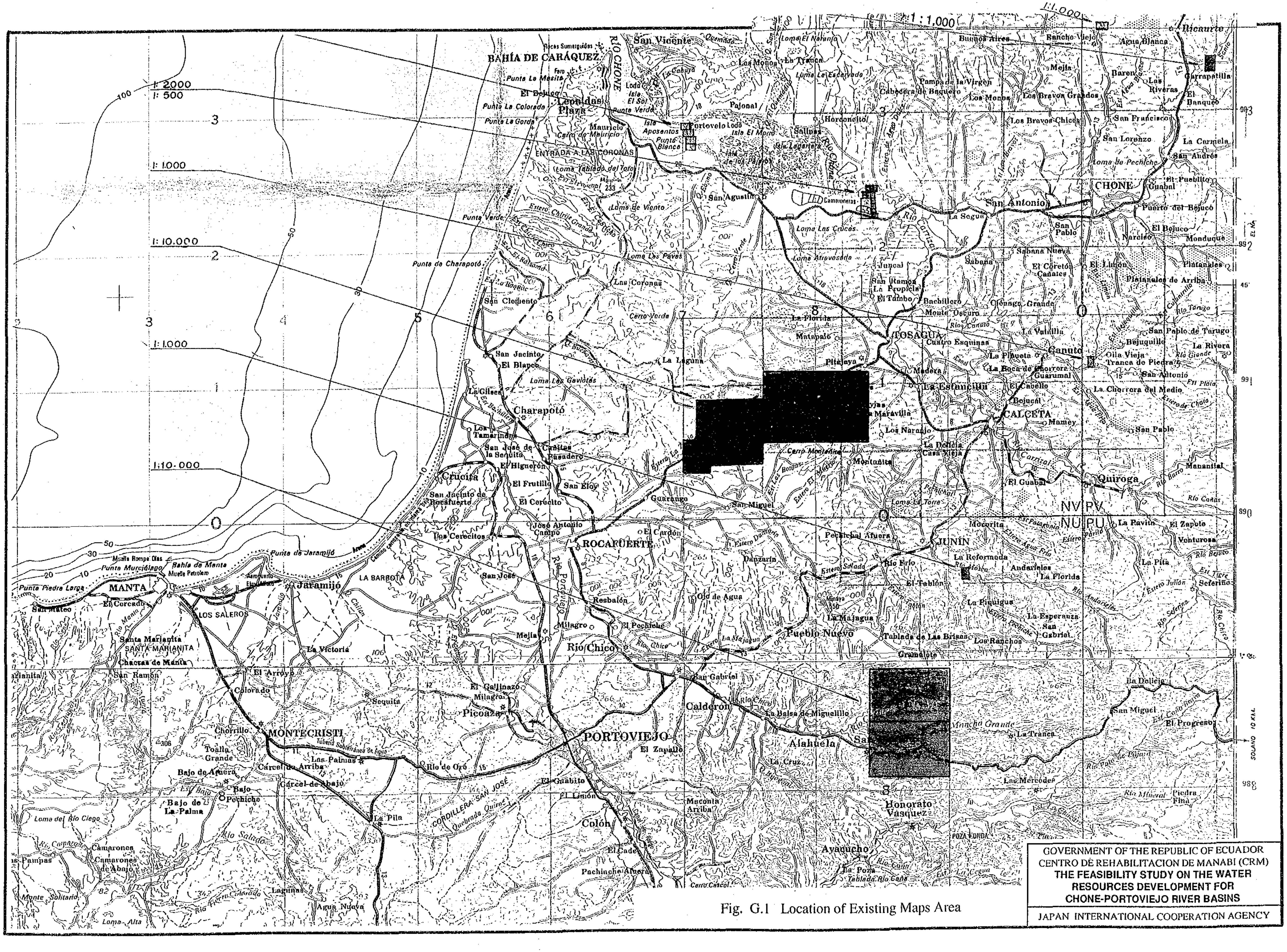
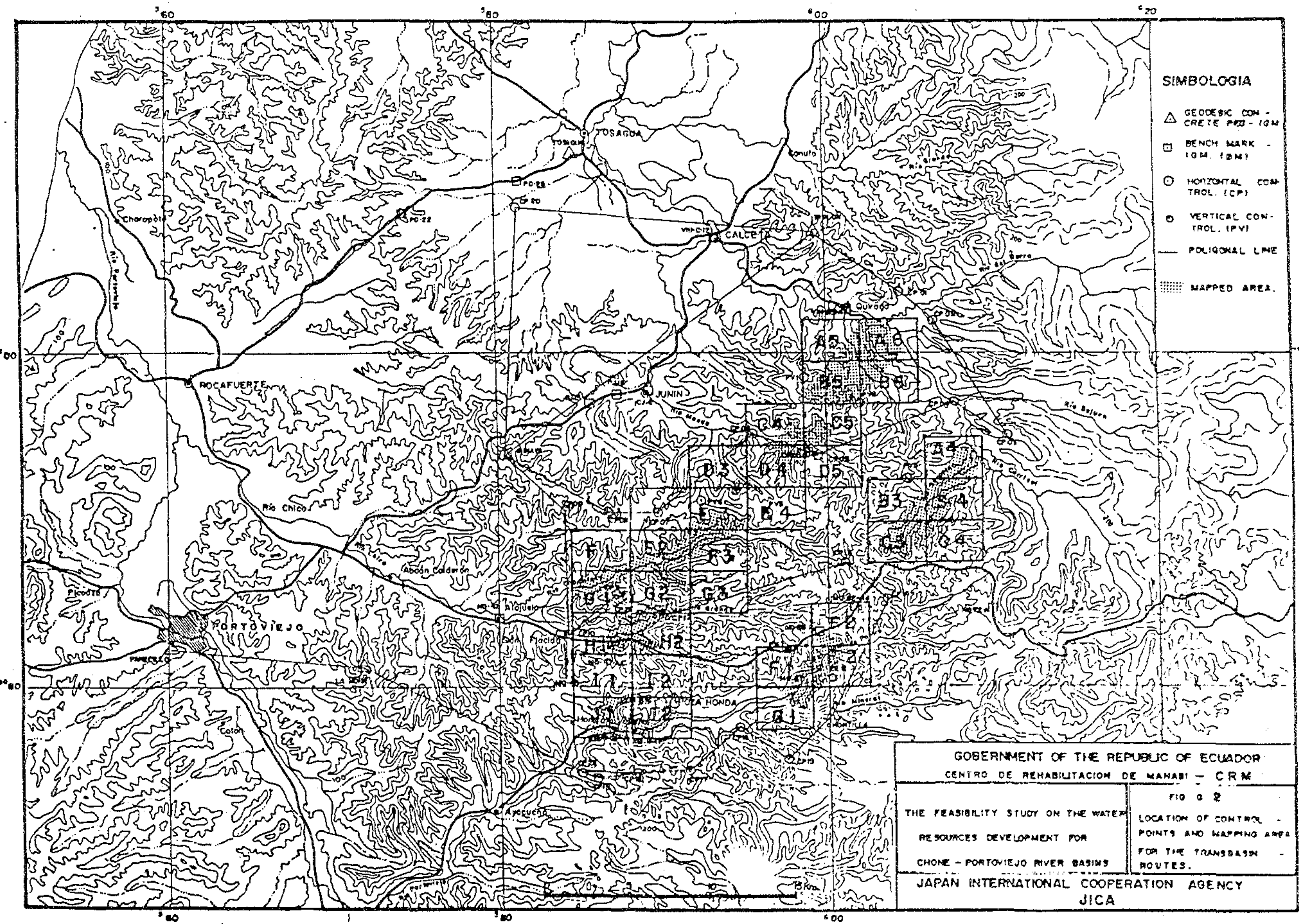



Fig. G.1 Location of Existing Maps Area

GOVERNMENT OF THE REPUBLIC OF ECUADOR
CENTRO DE REHABILITACION DE MANABI (CRM)
**THE FEASIBILITY STUDY ON THE WATER RESOURCES DEVELOPMENT FOR CHONE-PORTOVIEJO RIVER BASINS**

JAPAN INTERNATIONAL COOPERATION AGENCY




GOBERNMENT OF THE REPUBLIC OF ECUADOR

CENTRO DE REHABILITACION DE MANABI - CRM

THE FEASIBILITY STUDY ON THE WATER RESOURCES DEVELOPMENT FOR CHONE - PORTOVIEJO RIVER BASINS

FIG. 2

LOCATION OF CONTROL POINTS AND MAPPING AREA FOR THE TRANSBASIN ROUTES.

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JICA

# LEYENDA

| | |
|---|---|
| Puntos de Control GPS | Control Point by GPS |
| Puntos de Poligonal | Poligonal Point |
| Puntos de Control Vertical | Bench Mark |
| Puntos de Cotas | Spot Height |
| Edificios, Iglesia, Hospital | Building, Church, Hospital |
| Escuela, Fábrica, Cementerio | School, Factorie, Cemetery |
| Tanque | Tank |
| Estación de Bombeo | Pumping Station |
| Carretera Pavimentada | Paved Road |
| Carretera no Pavimentada | Road |
| Camino | Foot Path |
| Pared, Cerca | Wall, Fence |
| Torre de Transmision | Power Transmission Line |
| Puente, Alcantarillado | Bridge, Culvert |
| Terraplen o Dique | Embankment or Levee |
| Cortes | Cutting |
| Limite de Area Cultivada | Cultivation Boundary |
| Pastos | Pasture, Stockyards |
| Arrozales | Paddy Field |
| Cultivos o Haciendas | Cultivation or Farm |
| Pastrojos, Bambu | Bush, Bambo |
| Cultivos Permanentes | Orchard (Banana, Coffee, Cacao, etc.) |
| Pantanos | Swamp |
| Lagos, Lagunas | Pond, Lake |
| Rio Permanente | Perennial River |
| Rio Intermitente | Intermitent River |
| Arena, Grava | Sand, Gravel |
| Revestimiento | Revetment |
| Vertedero | Flood Weir |
| Compuerta | Flood Gate |
| Caidas | Water Fall |
| Protección de Riveras | Bank Protection |
| Dirección del Flujo | Flow Direction of Water |
| Farallón | Cliff |
| Deslizamiento | Land Slide |
| Depresiones | Depression Land |
| Curva de Nivel Indice | Index Contour |
| Curva de Nivel Intermedio | Intermediate Contour |
| Curva de Nivel Suplementario | Supplementary Contour |

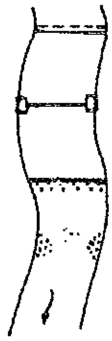
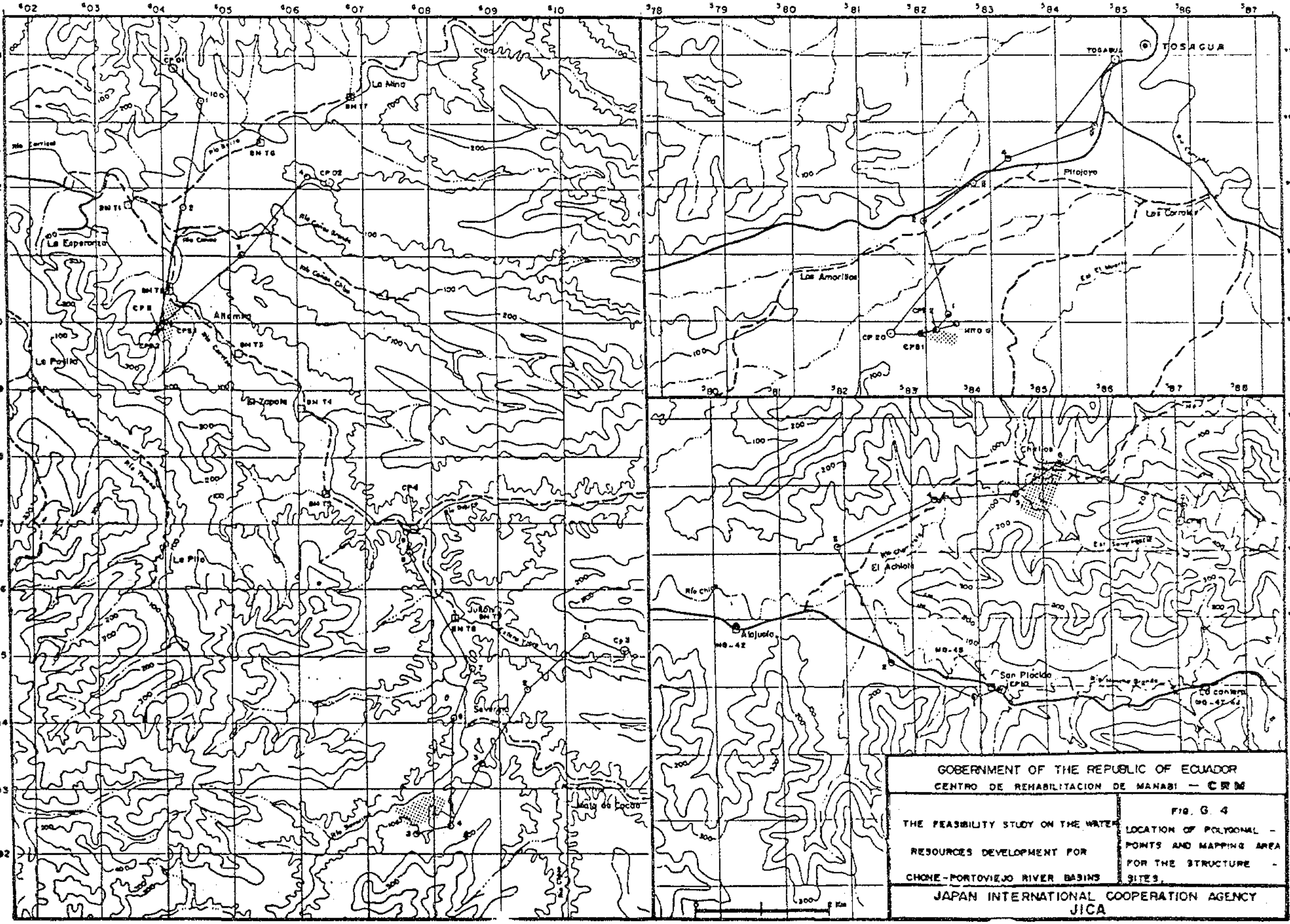


Fig. G.3 Map Symbols

GOVERNMENT OF THE REPUBLIC OF ECUADOR
CENTRO DE REHABILITACION DE MANABI (CRM)
THE FEASIBILITY STUDY ON THE WATER RESOURCES DEVELOPMENT FOR CHONE-PORTOVIEJO RIVER BASINS

JAPAN INTERNATIONAL COOPERATION AGENCY




GOBERNMENT OF THE REPUBLIC OF ECUADOR

CENTRO DE REHABILITACION DE MANABI — CRM

THE FEASIBILITY STUDY ON THE WATER RESOURCES DEVELOPMENT FOR CHONE-PORTOVIEJO RIVER BASINS

Fig. G. 4

LOCATION OF POLYGONAL - POINTS AND MAPPING AREA FOR THE STRUCTURE - SITES.

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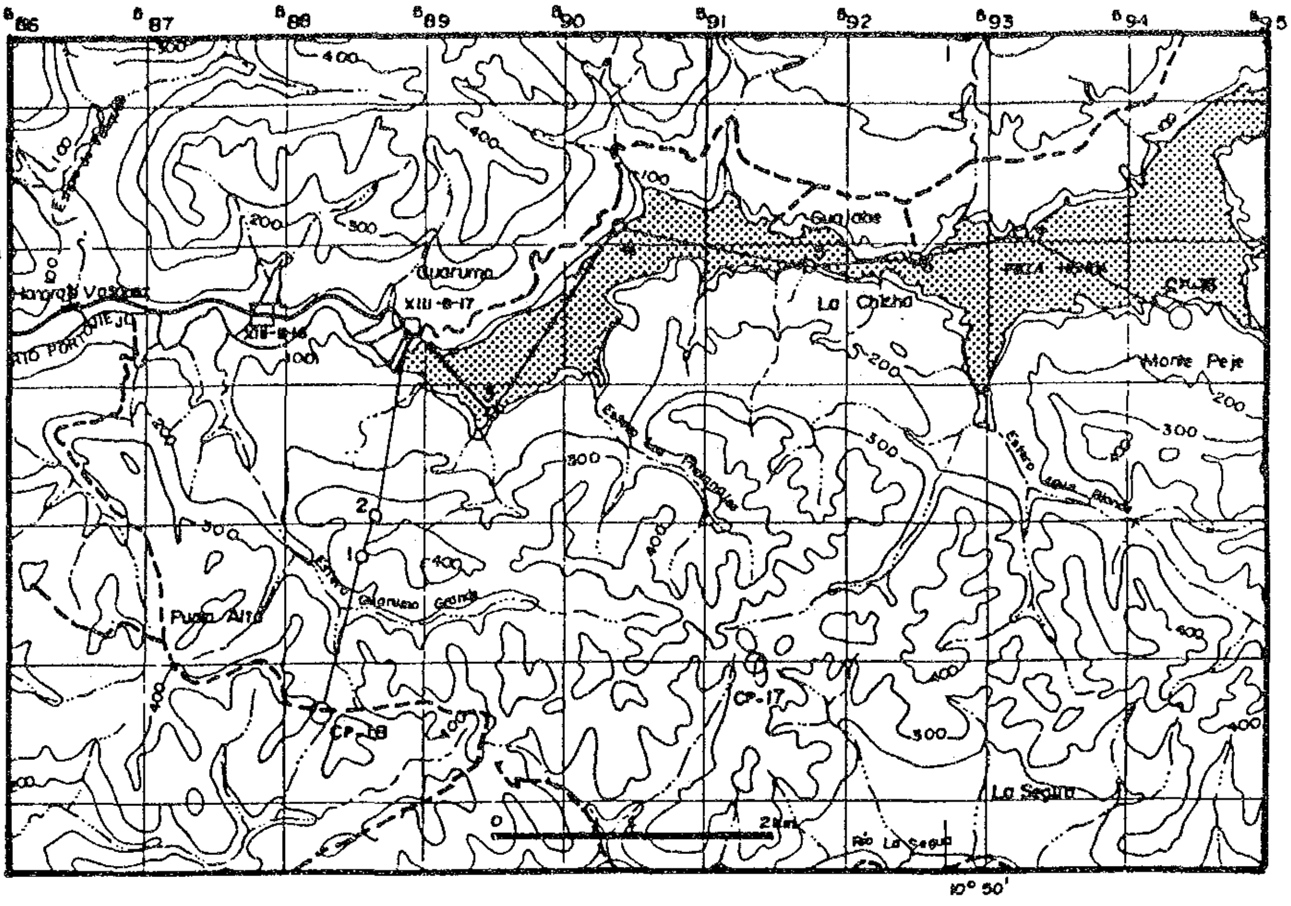


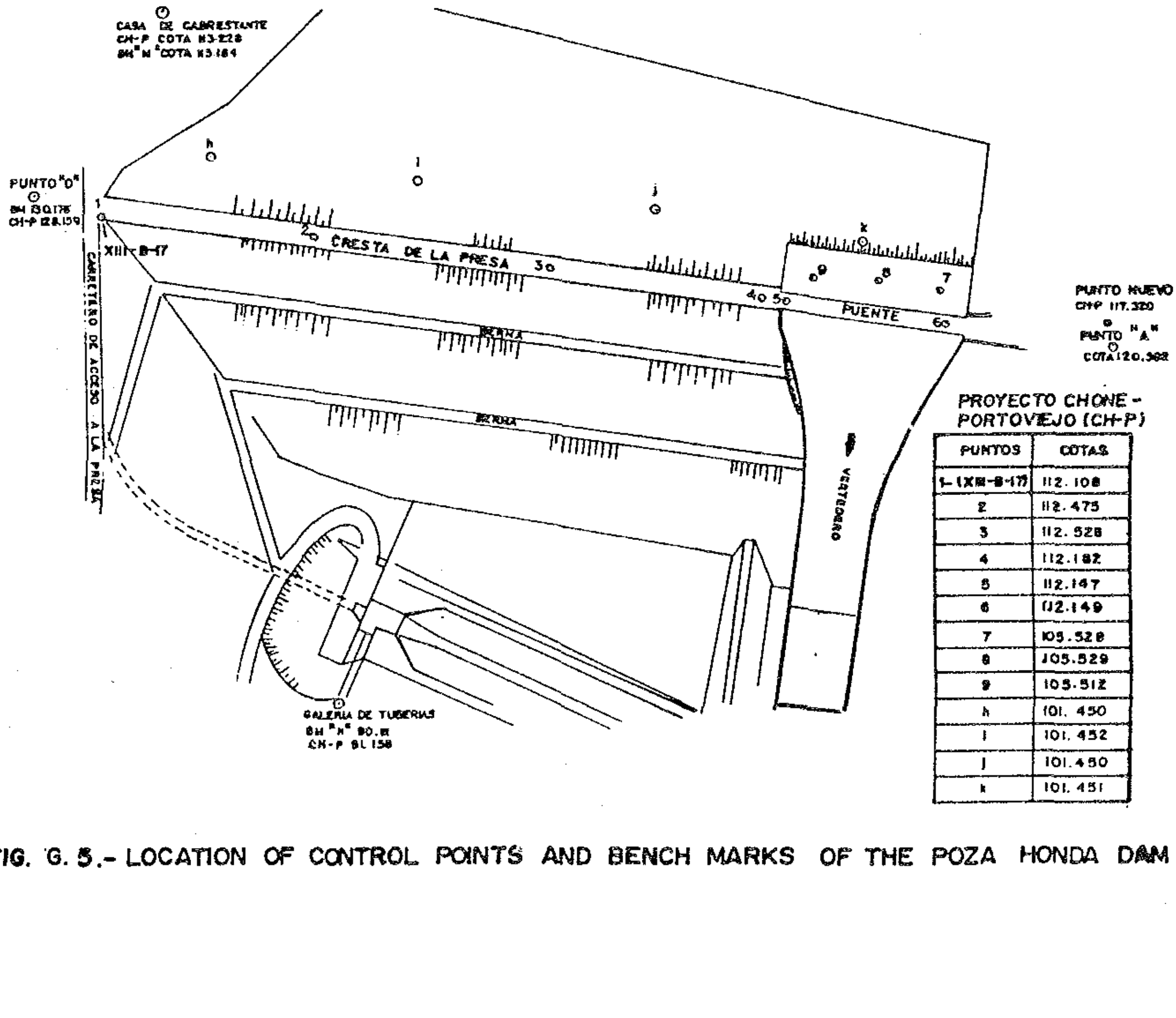


PROYECTO CHONE - PORTOVIEJO (CH-P)

| PUNTOS | COTAS |
|---|---|
| 1-(XIII-B-17) | 112.108 |
| 2 | 112.475 |
| 3 | 112.528 |
| 4 | 112.182 |
| 5 | 112.147 |
| 6 | 112.149 |
| 7 | 105.528 |
| 8 | 105.529 |
| 9 | 105.512 |
| h | 101.450 |
| i | 101.452 |
| j | 101.450 |
| k | 101.451 |

FIG. G.5.- LOCATION OF CONTROL POINTS AND BENCH MARKS OF THE POZA HONDA DAM

# Annex H

# GEOLOGY INVESTIGATION

# ANNEX H GEOLOGICAL INVESTIGATION

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## 1. INTRODUCTION

In this report geological matters in relation to the waterway facilities in 6 alternative schemes are described. Main facilities are tunnel, open channel, siphon and dam. In the 1'st phase of this feasibility study, seismic refraction survey was carried out in the dam site and tunnel route.

As a result of hydrological, civil and environmental studies in the 1'st phase, Alternative-5 scheme was esteemed as a most profitable one, therefore in the 2'nd phase, detailed boring work and soil mechanical test were performed for the design of tunnel and open channel in the scheme of Alternative-5. In addition to the boring works, permeability test and rock laboratory test were carried out. Especially for the object of rock samples in Guarango tunnel route, clay minerals has been analyzed by X-ray because there is possibility that these samples contain swelling clay minerals such as anhydrite and/or montmorillonite.

Geological ground surface investigation tracing the outcrops was carried out through all project area in order to make sure of geological characteristic and aerophoto interpretation was done as a supplemental work.

In the year of 1986 and 1987, Brazil and Spain studied geological condition of the water diversion tunnel by the method of boring work and those results of Brazilian and Spanish geological investigation were carefully reviewed for summarizing the engineering geology.

## 2. GENERAL GEOLOGY

Ecuador is divided geologically into 3 major regions i.e. the Oriente, the Andean range and the Costa. The Oriente means the eastern part of the land, it lies in the region of upstream reach of the Amazon and composed of old geological layer of metamorphic, sedimentary rock Paleozoic to Mesozoic (Cretaceous) in age.

The Andean range corresponds to so called the Andes cordillera, and huge and high volcanic mountains of Cretaceous from around 3,000 m to 6,000 m in elevation stretch widely. Lithology in this range is Andestic, basaltic rock and pyroclastic rock.

The Costa occupies the coastal region of the land where younger geological layer of sedimentary rock of Tertiary (Miocene to Pliocene) makes a gentle highly mountains.

Project area is situated in the Costa region. Geological basement of this area is Piñon formation of Cretaceous in geo-age and basalt in rock type. This layer outcrops at Picoaza town in the western vicinity of Portoviejo City. Major geological layer related to the project is Borbon, Onzole and Tosagua formation of Tertiary.

Borbon formation rock type which consists of sandstone and/or mudstone is distributed around the Daule-Peripa dam, and the mountain area of about 200 m higher in elevation. There is no clear difference between Borbon and Onzole formation.

Onzole formation is the layer which profoundly relates to engineering works in the project. In other word, this layer occupies the almost all project area except for local area of Guarango. Its rock type consists of very fine sandstone and/or mudstone.

Tosagua formation spreads in the area ranging from Guarango to Rocafuerte. This layer is composed of homogeneous calcareous mudstone. Gypsum, anhydrite and/or other swelling minerals are included in this layer.

From the view point of geotectonics, gentle anticline structure is supposed. It is assumed that the anticline axis NE to SW in direction extends from Portoviejo City toward Daule-Peripa Dam. However, since the gradient of anticline is very gentle, the dip of bedding actually appears horizontal in outcrops. Small scale of faults (1 km to 2 km in length) are supposed in some places, and regarding the fault system, 2 directions namely NE and SE are dominant.

As another geomorphological feature, appearance of cliffs are noted in the place of 200 m upper in altitude. As a result of observation of rocks, these cliffs consist of mudstone. Therefore it is considered that these were formed by the difference of erosion in the mudstone and underlying coarser sandstone.

## 3. CONTENTS OF GEOTECHNICAL INVESTIGATION

### 3.1 Seismic Refraction Survey

In the current study (1'st phase) seismic refraction survey has been selected for the field geological investigation. Seismic refraction survey of 49 lines, 40 km long in total has been carried out in the tunnel routes and Chirijos damsite. Location and work quantity are shown in Figure H.3, and survey results are summarized as follows.

| Site | P wave Velocity (km/sec) | Depth (m) | Geological Type |
|---|---|---|---|
| Tunnel | 0.3 - 0.5 | 0 - 3 | Top soil |
| Alternative 1 | 0.5 - 1.0 | 3 - 10 | Decomposed soil and colluvial |
| 3 & 5 | 1.0 - 1.5 | 10 - 15 | Weathered rock |
| | 2.1 - 2.3 | 15 - | Fresh rock |
| Tunnel Guarango | 0.3 - 0.5 | 0 - 3 | Top soil |
| | 0.6 - 0.9 | 3 - 15 | Decomposed soil |
| | 0.9 - 1.5 | 15 - 25 | Weathered rock |
| | 2.1 - 2.3 | 25 - | Fresh rock |
| Chirijos dam | 0.3 - 0.5 | 0 - 5 | Top soil |
| | 0.6 - 1.1 | 5 - 20 | Decomposed soil, alluvial and colluvial |
| | 1.1 - 1.5 | 10 - 30 | Weathered rock |
| | 2.1 - 2.3 | 30 - | Fresh rock |

Note: Decomposed soil means heavily weathered rock layer into soil.

### 3.2 **Boring** (Refer to Fig. H.5)

Boring work (6 holes and 210 m long in total) was carried in the site of Alternative-5 scheme (pumping station/head tank, siphon and inlet, outlet of tunnel). Actual location and contents of boring work are shown in Table H.1, and the results are summarized as follows.

(1) Foundation rock for pumping station, head tank and tunnel are composed of mudstone, sandstone and those alternation. These rocks are classified into soft rock, CL class in the Japanese rock classification which correspond to IV class in the Beniawski's classification (Refer to Table H.2).

(2) Thickness of soil layer (alluvium and colluvium) is 2 m at the pumping station, 5 m at the head tank site and 9 m at siphon site respectively.

(3) Thickness of soil layer (colluvium) is about 10 m around the portal place of tunnel from Caña Dulce to Poza Honda. On the other hand, in the portal place of tunnel of Poza Honda to Mancha Grande route, weathered rock zone is rather deep as a consequence thickness of soil layer is estimated at 20 meters.

(4) There is a tendency that mudstone in the tunnel route from Poza Honda to Mancha Grande is loosened by weathering action, in other words, this mudstone becomes gradually loose after excavation if it is left in the natural condition.

(5) The value of R.Q.D. is 80 on an average, that is to say there are few cracks in this rock layer.

(6) The level of underground water is shown in the following table.

| Hole No. | Site | Underground water level |
|---|---|---|
| B1 | Pumping station | Dry |
| B2 | Siphon | GL - 3 m |
| B3 | Caña Dulce Tunnel Inlet | GL - 15 m |
| B4 | Pata de Pájaro (Poza Honda) Tunnel Outlet | GL - 14 m |
| B5 | Guajabito (Poza Honda) - Tunnel Inlet | GL - 8 m |
| B6 | Mancha Grande - Tunnel Outlet | GL - 10 m |

### 3.3 **Permeability Test** (Refer to Fig. H.6)

Permeability test in-situ was carried out using the boring hole. In the site of pumping station and siphon the test was done by the free flow method, while Lugeon Test was selected in the tunnel site. Test results are summarized as follows.

| Hole No. | Site | Geological Type | Permeability Coefficient k (cm/sec) |
|---|---|---|---|
| B-1 | Pumping Station Head Tank | Colluvium | $6.3 \times 10^{-4}$ |
| B-2 | Siphon | Alluvium | $9.6 \times 10^{-3}$ - $2 \times 10^{-2}$ |
| B-3 | Tunnel | Mudstone | $2.4 \times 10^{-4}$ - $5.5 \times 10^{-5}$ |
| B-4 | " | " | $1.8 \times 10^{-5}$ - $7.5 \times 10^{-6}$ |
| B-5 | " | " | $1 \times 10^{-6}$ |
| B-6 | " | " | $3.5 \times 10^{-4}$ |

In the site of pumping station/head tank and siphon geological type is colluvial and alluvial soil, as a result permeability is high.

The permeability of the mudstone in relation to the tunnel is generally sufficient low ($k = 1 \times 10^{-5}$ cm/sec order), although in the partial cracky zones, coefficient of permeability of $1 \times 10^{-4}$ cm/sec order are measured.

### 3.4 **Rock Test** (Refer to Fig. H.5)

In relation to the tunneling work, laboratory rock test was carried out for the purpose of ascertaining the strength of rock. Boring core samples are selected for the examination. Test items are bulk density, water absorption and unconfined uncompressive strength. In addition to these items, especially for rock samples in the Guarango tunnel route, clay minerals are analyzed by X-ray in order to confirm existence of expansive minerals such as gypsum, anhydrite and/or montmorillonite. Test results are summarized as follows.

(1) Bulk density ranges 1.9 g/cm$^3$ to 2.1 g/cm$^3$, which shows average value in the soft rock.

(2) Regarding unconfined compressive strength in relation to tunnel, average value of qu is 60 kg/cm$^2$, which shows rather weak condition than it appears.

(3) Relatively high rate of water absorption is shown (20 - 30%), however rate of volume change as to swelling is very low (less than 1%).

(4) In the rock sample of Guarango tunnel route, expansive mineral (montmorillonite) has been detected.

| Hole No. | Sampling Depth | Site | Result of Rock Test | | | | |
|---|---|---|---|---|---|---|---|
| | | | γ g/cm3 | qu kg/cm2 | Wab % | VC % | Rock Type |
| B-1 | 29 m | Pump Station/Head Tank | 1.9 | 71 | 22 | 0.04 | SS |
| B-2 | | Siphon | 1.9 | 133 | 30 | 0.27 | MD |
| B-3 | | Caña Dulce (Inlet) | 2.0 | 45 | 24 | 1.10 | MD |
| B-4 | | Poza Honda (Outlet) | 2.1 | 73 | 22 | 0.38 | MD |
| B-5 | 29 m | Poza Honda (Inlet) | 1.9 | 47 | 21 | 0.80 | MD |
| B-6 | | Mancha Grande (Outlet) | 2.1 | 33 | 20 | 0.50 | MD |
| *ST-2 | 40 m | Guarango | 2.0 | 30 | 30 | 5.00 | MD |

Note: *ST-2 : Boring by Spanish Study Team in 1986 (6 years ago)
γ : Bulk density, qu : unconfined compressive strength
Wab : Water absorption, VC : Volume change by swelling
SS : Sandstone, MD : Mudstone

### 3.5 **Soil Mechanical Test** (Refer to Table H.4, H.5)

As for the layer along the open channel route from Serverino to Caña Dulce, laboratory soil mechanical test was carried out. Samples were collected by the method of shelby sampler (thin wall tube sampler) and block sampling of test pit. Actual items of examination and those specification (ASTM No.) are shown in Table H.4.

In the current test, examination regarding the dispersive and expansive clay is especially conducted. Because the soil (clay) in this area has a serious tendency of failure by swelling in the rainy season. Those test items are potential volume, swelling, pinhole, double hydrometer test and chemical analysis.

Test results are summarized in Table H.5.

## 4. GEOLOGICAL CONDITION AND ENGINEERING GEOLOGY IN PROJECT SITE

In every project site geological condition and engineering geology are summarized as follows. Rock type is described based on the observation of outcrop in geological mapping and boring core samples. Rock classification for dam foundation is ranked on the basis of Japanese standard, and with regard to rock classification for tunnel engineering, three criteria are adopted, i.e. (1) Japanese standard (2) Rock classification based on the seismic P-wave velocity, and (3) Beniawski's classification as shown in Tables H.1, H.2 and H3. The unconfined compressive strength and static elastic modules are assumed in consideration of the result of laboratory rock test.

While, engineering properties of soil layer along the open channel are mentioned on the basis of the result of soil mechanical test as shown in Table H.5.

### 4.1 Diversion Tunnel from Caña Dulce to Poza Honda

(Refer to Fig. H.7 and H.8)

The tunnel with a 3.5 m in diameter and about 11 km in length is planned. Tunnel route is located in the mountainous area from 200 m to 400 m in elevation. In reference to the result of seismic refraction survey and boring, rock type is composed of mainly mudstone in tunnel formation level except for portal position. On the other hand, colluvial and weathered mudstone (soil layer) of 10 to 20 m in thickness cover the ground surface in the portal position.

Rock classification and main engineering properties are shown as follows:

| Engineering Properties | | Portal position Total length 350m | Inside part of tunnel |
|---|---|---|---|
| Rock type | | Colluvial | Sandy mudstone |
| Rock class | | D (soil) | CL (soft rock) |
| P wave velocity | Vp (km/sec) | 1.5 | 2.1 - 2.3 |
| Unit weight | $\gamma$ (g/cm$^3$) | 1.7 | 2.1 |
| Unconfined compressive strength | qu (kgf/cm$^2$) | 10 - 20 | 60 - 100 |
| Static elastic modulus | Es (kgf/cm$^2$) | 2,000 | 10,000 - 12,000 |
| Permeability coefficient | k (cm/sec) | $1 \times 10^{-3}$ - $1 \times 10^{-4}$ | $1 \times 10^{-5}$ |

This sandy mudstone shows soft solidity to some extent, but massive and rarely cracked. As a result of rock test, unconfined compressive strength (qu) is relatively small contrary to the appearance of solidity (30 kg/cm$^2$) in minimum, (60 kg/cm$^2$) on average. Since this core sample is selected in the portal position (overburden 30 m in thickness), the value of qu is possibly increased in the inner part of mountain (assumed to be 150 kg/cm$^2$).

Water flow by tunnel excavation seems to be a little based on the permeability coefficient (k = 1 x $10^{-5}$ cm/sec). Although it is assumed that minor cracky zone exist, large scale of fractured zone is scarcely found out.

Judging from the solidity of the rock and the value of qu, steel support is required for the colluvial and weathered rock layer in the portal position. However, with regard to actual portal work, it is not critical work as far as judging from the topographic condition and overburden thickness.

## 4.2 Diversion Tunnel from Poza Honda to Mancha Grande

(Refer to Fig. H.7 and H.8)

The tunnel with a 2.5 m in diameter and about 4 km in length is planned. Tunnel route is located in the steep mountainous area of 200 m to 400 m in elevation except the portal position. On the other hand, around the portal position (both inlet and outlet) topographic condition shows gentle slope where the colluvial deposit (landslide-like talus) and heavily weathered rock layer cover the ground surface.

In the basis of the result of seismic refraction survey and boring, geological composition in relation to the tunnel is divided into 2 kinds, i.e. colluvium or weathered mudstone in the portal positions and mudstone in the inner part of tunnel. Rock classification and engineering properties are shown as follows.

| Engineering Properties | | Portal position 450 m in length | Inner part of tunnel |
|---|---|---|---|
| Rock type | | Colluvial weathered rock | Mudstone |
| Rock class | | D | CL |
| P wave velocity | Vp (km/sec) | 1.5 | 2.1 - 2.3 |
| Unit weight | $\gamma$ (g/cm$^3$) | 1.7 | 2.1 |
| Unconfined compressive strength | qu (kgf/cm$^2$) | 10 - 20 | 60 - 100 |
| Static elastic modulus | Es (kgf/cm$^2$) | 2,000 | 10,000 - 12,000 |
| Permeability coefficient | K (cm/sec) | 1 x $10^{-4}$ | 1 x $10^{-5}$ |

Similar to the tunnel from Caña Dulce to Poza Honda this mudstone shows crackless feature and large scale of fractured zone is not found, although minor shearing zone occurs locally. Since permeability is small, water flow by tunnel excavation is a little.

According to the observation of boring core, this mudstone is apt to become loose exposed to air, which means that steel support and/or coating work after excavation by instance shotcrete are required.

Moreover for the portal work, as colluvium and weathered rock zone cover the ground widely, closer arrangement of steel support and/or thicker concrete lining are needed.

### 4.3 Diversion Tunnel from Altamira to Portoviejo River (Refer to Fig. H.9)

This tunnel route is planned from Altamira pumping station to Portoviejo River (downstream of the Poza Honda dam). Tunnel changes to open channel in three locations on the way (Tributary La Abeja, River Chamotete and River Chico). Diameter and length of tunnel are 3.1 m and 21 km.

Tunnel route is selected in the mountainous area from 200 m to 400 m in elevation.

Geological composition (rock type) in relation to tunnel is divided into 2 kinds. Those are colluvial or weathered sandy mudstone in the portal positions and sandy mudstone inside part of tunnel. Rock classification and engineering properties are shown as follows.

| Engineering Properties | | Portal position Total 8 portals 1,500 m in length | Inside part of tunnel |
|---|---|---|---|
| Rock type | | Colluvial weathered rock | Sandy mudstone |
| Rock class | | D | CL |
| P wave velocity | Vp (km/sec) | 1.5 | 2.1 - 2.3 |
| Unit weight | $\gamma$ (g/cm$^3$) | 1.7 | 2.1 |
| Unconfined compressive strength | qu (kgf/cm$^2$) | 10 - 20 | 60 - 100 |
| Static elastic modulus | Es (kgf/cm$^2$) | 2,000 | 10,000 - 12,000 |
| Permeability coefficient | k (cm/sec) | $1 \times 10^{-4}$ | $1 \times 10^{-5}$ |

Geological condition for tunneling work is similar to the tunnel route from Caña Dulce to Poza Honda. The rock shows crackless feature and large scale of fractured zone is not found, in addition, permeability is low. However, steel support will be required for weathered rock zone.

### 4.4 **Diversion Tunnel from Amarillos to Guarango** (Refer to Fig. H.10)

This tunnel is planned connecting with long open channel from La Esperanza dam to Amarillos pumping station. Length of tunnel is about 6 km and its diameter is 2.5 m. Tunnel passes the gentle hill of Tosagua formation from 100 to 150 m in elevation.

In this area, weathering is so heavy and deep. Outcrop of rock is not found. It is critical characteristic that the rock in this area contains swelling clay minerals such as montmorillonite and anhydride. According to the boring (carried out by Spain in 1986), rock type consist of calcareous mudstone.

Refering to the seismic survey and boring core observation, geological type in relation to tunnel is divided into following 3 kinds.

(1) Weathered mudstone with much swelling minerals (in the portal positions, 300 m in total length).

(2) Mudstone slightly weathered with moderate swelling minerals (Upstream side of tunnel, 250 m in length).

(3) Fresh mudstone with a little swelling minerals (5,500 m in length).

Engineering properties of each geological type (1), (2) and (3) are shown as follows.

| Geological Type | (1) Weathered mudstone with swell mineral | (2) Mudstone slightly weathered with swell mineral | (3) Fresh mudstone with a little swell mineral |
|---|---|---|---|
| Rock class | E (soil) | D (very soft) | CL (soft) |
| Vp (km/sec) | 0.9 - 1.5 | 1.5 | 2.1 - 2.5 |
| $\gamma$ (g/cm$^3$) | 1.6 | 1.7 | 2.1 |
| qu (kgf/cm$^2$) | 10 | 30 | 60 |
| Es (kgf/cm$^2$) | 1,000 - 2,000 | 5,000 | 10,000 - 12,000 |
| k (cm/sec) | $1 \times 10^{-4}$ | $1 \times 10^{-4}$ | $1 \times 10^{-5}$ |

The key point of engineering geology in this tunnel route is occurrence of swelling minerals. As a consequence very careful supporting system and thick concrete lining should be carried out.

### 4.5 Diversion Tunnel from Daule-Peripa to La Esperanza (Refer to Fig. H.11)

This tunnel is planned from the Conguillo river in the Daule-Peripa reservoir to Membrillo river in the La Esperanza reservoir. Tunnel length is about 8.3 km and its diameter is 3.7 m. In the year 1986 Brasilian team investigated the geology of tunnel route by borings.

Rock type in relation to tunnel level consists of fine sandstone and/or mudstone. This rock is classified into medium rock from the view point of R.Q.D. and grade IV-III on the basis of Bieniawski's rock classification and it can be applied to the rock of CL to CM class in Japanese criteria. Main engineering properties are shown as follows.

| | |
|---|---|
| Unit weight | $\gamma$ = 2.1 g/cm$^3$ |
| Unconfined compressive strength | qu = 60 - 100 kg/cm$^2$ |
| Static elastic modulus | Es = 10,000 - 12,000 kg/cm$^2$ |
| Permeability coefficient | K = $1 \times 10^{-4}$ - $1 \times 10^{-5}$ cm/sec |

According to boring core and outcrop of rock, it presents soft rock, however massive and crackless condition, furthermore serious fractured zone is not found.

Since permeability coefficient indicates $10^{-4}$ cm/sec order in almost all part of tunnel, a little quantity of water flow is foreseen and it is assumed that the quantity of water flow is relatively much (20 liter per minute) in the following places where tunnel passes under the tributary. Those are tributary Perro (about 1.2 km from inlet point) tributary Canales (about 2.2 km from inlet point), tributary Lozas (about 5.8 km from inlet point) and tributary Mulatos (about 8.2 km from inlet point).

Judging from the solidity of rock, steel support is required for weathered rock zone.

It is expected that almost all section of the tunnel passes the fresh rock layer above mentioned, however, within the portal position of the tunnel, rock is weathered and loosened (D class in classification), where close arrangement of supporting is required. Its length is estimated at about 300 m in total.

### 4.6 Diversion Tunnel from Downstream of Daule-Peripa to Poza Honda
(Refer to Fig. H.12)

This tunnel is the latter part of the waterway from Lisondro river (at about 30 km downstream of the Daule-Peripa dam) to Mineral river (in the Poza Honda reservoir). Tunnel, 11.2 km long with diameter of 3.8 m, is designed connecting to the pipe line.

Geological condition in this tunnel route was also investigated by way of borings of Brasilian team in 1986.

Through the whole route tunnel passes the very fine sandstone and/or sandy mudstone of the Onzole formation. This rock is classified into CL to CM (soft rock in solidity) and then engineering properties are nearly same as those in the tunnel route from Daule-Peripa to La Esperanza (Refer to article 4.5).

As a result of ground surface mapping, large scale of fractured zone is not found. In addition, there are few tributaries in the tunnel route and permeability is small, consequently it is judged that problem of water for tunneling work is small. However, steel support is required because the rock is soft in solidity.

## 4.7 **Chirijos Dam** (Refer to Fig. H.13 and H.14)

(1) Dam type

Fill type dam of 35 m in height (from river level), 40 x $10^6$ $m^3$ in volume is planned.

(2) Geological condition

In the damsite, riverbed is very wide and reverse trapezoidal topography is shown. Slope of both banks is about 30 degrees. Base rock consists of mudstone, and it is covered thick by decomposed soil in both banks (about 20 m thick) and alluvial soil in the riverbed (15 to 20 m thick). Below these soil layer, weathered mudstone is underlaid with thickness of 10 to 20 m. Fresh rock lies 30 to 40 m deep from ground surface. Engineering properties of each layer are shown as follows.

| Engineering properties | | Alluvial and decomposed soil | Weathered mudstone | Fresh mudstone |
|---|---|---|---|---|
| Rock class | | - | D | CL |
| Unit weight | γ (g/$cm^3$) | 1.6 | 1.7 | 2.1 |
| Cohesion | C (kgf/$cm^2$) | 0.1 | 1.0 | 5.0 |
| Internal frictional angle | ø (degree) | 15 | 30 | 30 |
| Unconfined compressive strength | qu (kgf/$cm^2$) | 1.0 | 10 | 60 - 100 |
| Static elastic modulus | Es (kgf/$cm^2$) | 200 | 2,000 | 12,000 |
| Permeability coefficient | k (cm/sec) | 1 x $10^{-3}$ | 1 x $10^{-4}$ | 1 x $10^{-5}$ |

(3) Engineering matters for dam foundation

Judging from the strength of fresh mudstone, fill type dam is recommended. Alluvial soil and weathered rock layer is too thick for the gravity dam. In addition, slope stability is to be considered. Especially in the left bank, slope protection work will be required.

(4) Embankment materials

It is judged that mudstone near the dam site is suitable for impervious material and volume is enough. On the contrary, rock and sand material cannot be found out near the site. The nearest location of rock material existing quarry (town Picoaza) is about 40 km far from the damsite. In case of using this quarry, sand must be produced by crushing.

On the other hand, natural material of sand and gravel are found in the Quevedo town, about 150 km far from this site.

## 4.8 Severino Pumping Station

Geological condition near this pumping station appears good, that is why relatively hard sandstone, class CL-CM outcrops in the backside of proposed pumping station site. Although some boulder layer (talus) about 5 m thick overlies near the river side (Severino river), foundation of facilities is easily placed on the fresh rock layer. Uncompressive strength and permeability are 130 $kg/cm^2$ and $1 \times 10^{-5}$ cm/sec, respectively.

## 4.9 Open Channel & Siphon from Severino to Caña Dulce

(Refer to Fig. H.7 and H.15)

### (1) Open Channel Route

Geological type in relation to the open channel facilities consist of colluvial decomposed soil (heavily weathered mudstone) and weathered rock layer. As a result of test pitting and geo-surface inspection, these soil layer have approximately 4 m to 5 m in thickness and gradually transferred into weathered rock layer.

Soil mechanical test was carried out in the colluvial and decomposed soil layer, 2 meters deep from ground surface.

Features of engineering properties of the soil are shown as follows.

(a) These soil is classified into CH and MH (Clay-silt) on the basis of unified soil classification.

(b) There is a possibility of expansive soils from the view point of shrinkage and swelling factor, in some places.

(c) Silt and clay show the permeability coefficient of some 1 x $10^{-6}$ cm/sec to 1 x $10^{-7}$ cm/sec, therefore it is classified into impervious soil, so none seepage is expected from the canal.

(d) The suitability of embankment material should be judged in accordance with the degree of volume change (VC) as indicated in Table H.5 and H.7. As long as this criteria is applied for soils regarding the route of canal, these silt and clay are not suitable for embankment material because severe and harmful shrinkages are expected.

(e) With regard to the characteristics of soil in a sense of expansion and its suitability as foundation material, two (2) test were carried out, they are: PVC and swelling test and also index properties were taken into account, as shown as follows:

| Test Pit Number | WL % | PI % | % Passing # 200 | Expecting Swelling Potential | Swelling Classification according to: PVC | Swelling Pressure | Volume Change (V) | Possible Classification |
|---|---|---|---|---|---|---|---|---|
| C-1 | 89 | 36 | 100 | High | NC | Low | Low | NC |
| C-2 | 75 | 26 | 97 | Medium | VC | Medium | Medium | C |
| C-3 | 71 | 35 | 87 | High | VC | Low | High | C |
| C-4 | 91 | 43 | 97 | Ditto | C | Medium | Ditto | C |
| C-5 | 76 | 23 | 93 | Medium | VC | Low | Medium | C |
| C-6 | 87 | 37 | 96 | High | C | Medium | High | C |
| C-7 | 46 | 12 | 34 | Low | NC | Low | Low | NC |
| C-8 | 69 | 20 | 75 | Medium | VC | Ditto | Medium | C |
| C-9 | 67 | 22 | 89 | Ditto | VC | Medium | High | C |

It is possible to state that these silt and clay along the open channel route show critical swelling condition, consequently concrete lining will be damaged, for this reason it is recommended some countermeasures such as: replacing the swelling soil with non swelling soil or changing the properties of expansive soil by chemical injection or increasing the density of soil by compaction control. It is strongly recommended for the D/D, to perform more detailed soil investigation, layer by layer and very controlled laboratory swelling test.

(f) Average value of natural moisture contents (Wn) is 32%, while average value of optimum moisture content (OMC) is 29%, then Wn is larger than OMC. Thus, earth moving works, particularly embankment work should be done in dry season only and all compaction works have to be performed at dry densities.

(g) As far as the result of double hydrometer test and total dissolved salt analysis, clay-silt of test pits C-3 and C-4 show some degree of dispersibility but not so high consequently, it seems that those soils are not so dangerous in order to use as embankment material from the view point of erosion and piping. However pinhole tests were performed, and these soils show nondispersive condition.

(h) According to the results of triaxial test, considering the slope stability analysis, it is possible to expect that mostly of soil have angle of internal friction ranging from 5° to 25° and cohesion from 5 ton/$m^2$ to 13 ton/$m^2$ which keep stable slope. For the gradient of slope from 1:1 to 1:1.5 are recommended.

(2) Siphon site

Siphon site was investigated by mean of one borehole (B2), standard penetration test and laboratory test were also executed. The N-value goes from 7 to 25 in the alluvial layer of 9 m. The most suitable layer for the siphon to be placed is that with N between 10 and 25, that means between 7 m and 8 m depth and also this layer has good bearing capacity. The permeability is quite high (k = 3.7 x $10^{-3}$ cm/sec) and then good drainage system has to be provided during construction.

(3) Head tank

SPT was performed and N-values varies from 14 to 34, and the rock top is found at 5.30 m below the ground surface. From the view point of N-value it is recommended that the head tank is placed into the rock layer.

## 4.10 Earth and Rock Materials

### 4.10.1 Dam embankment materials

Good impervious material originated from weathered sandstone and/or mudstone is abundantly obtained in the vicinity of the damsite. On the other hand, with regard to sand (filter) and rock material, two possibilities are considered, i.e.

(1) Use of existing quarry (town Picoaza), and (2) use of river deposit (town Quevedo). Conditions of each site are summarized as follows.

| Site | Geo-Type | Quality | Quantity | Distance |
|---|---|---|---|---|
| (1) Picoaza | Basalt | Good<br>crushing for sand | Enough | 40 km |
| (2) Quevedo | Andesite<br>origin sand gravel | Good | Enough | 160 km |

### 4.10.2 Concrete aggregate

As well as sand and rock materials above mentioned, regarding concrete aggregate two alternatives are considered i.e. (1) use of existing quarry (town Picoaza), and (2) use of river deposit (town Quevedo).

# 5. GEOLOGICAL CONSIDERATION FOR DESIGN AND CONSTRUCTION

## 5.1 New Austrian Tunnelling Method (NATM)

For the tunneling work intended for the soft muddy rock, NATM is regarded to be more effective for prevention of tunnel collapse. NATM is a kind of supporting work by shotcrete with rock bolt after excavation and in accordance with the rock strength, arrangement of shotcrete, rock bolt and steel support are designed. In this tunneling work, the following 4 types are selected.

(1) shotcrete + rock bolt, rock bolts are driven in the upper part of the tunnel + concrete lining
(2) shotcrete + rock bolt, rock bolts are driven in both upper part and side wall of the tunnel + concrete lining
(3) shotcrete + rock bolt + steel support (H 125 spaced 120 cm) + concrete lining
(4) shotcrete + rock bolt + steel support (H 125 spaced 100 cm) + concrete lining

In case of hard rock, steel support can be omitted, however with regard to this tunnel unconfined compressive strength is 60 to 100 kg/cm$^2$ therefore steel support is also needed in some places. Especially in the portal position and fractured zone (assumed qu = 30 kg/cm$^2$), close spacing steel support is added.

In the tunnel from Daule-Pelipa to Esperanza, Caña Dulce to Poza Honda and Poza Honda to Mancha Grande, regarding the arrangement of support 4 patterns (1)~(4) are designed. On the other hand in the tunnel of Guarango, throughout the tunnel, steel support should be placed more closely in addition to shotcrete + rock bolt that is why swelling minerals is contained.

### 5.2 Earth Work for Open Channel

As mentioned in the article 4.9, geological type in relation to the open channel are composed of clay-silt and weathered rock (mainly mudstone). From the view point of earth work engineering characteristics of those geological types are shown in detail as follows.

(1) Clay-silt layer has a possibility of expansive in some places which is critical for the earth work, in case of water absorption.

(2) Weathered rock layer underlying below the clay-silt layer is firm enough for the foundation of the canal.

(3) In case that canal foundation level is upper than weathered rock line level, replacement of clay-silt will be considered.

(4) Clay-silt itself is not suitable for embankment material.

(5) Weathered rock is available for embankment material, moreover tunnel excavation rock is useful for embankment.

(6) Base course setting by hard crushing stone under the concrete of canal is effective for stability of the canal.

(7) Both clay-silt and weathered rock have relatively strong cohesion in dry condition, however in wet condition its cohesion is extremely decreased, as a

consequence covering work such as sodding and/or shotcrete with drain holes is needed for the cutting slope.

(8) Considering the swelling, prevention work against the water permeation through the clay-silt layer will be required in some places.

# TABLES

## Table H.1 Content of Boring, Permeability Test & Rock Test

| HOLE No. | COORDINATES | | ELEVATION (masl) | DEPTH (m) | El at tunnel formation (masl) | Lugeon Field Permeability Test interval (m) | S.P.T. interval (m) | Lefrank Field Permeability Test interval (m) | Undisturbed Samping Interval (m) (Shelby) | Rock Test Core Sampling Depth (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | E | | | | | | | | |
| B – 1 (Pumping Station) | 9,892,670 | 607.534 | 95.29 | 30 | – | 25 - 30 | Continuous on soil through the rock | 0.8 - 2 | 3 - 4<br>5 - 6<br>7 - 8 | 29.5<br>1 |
| B – 2 (Siphon) | 9,890,635 | 605.835 | 70.79 | 20 | – | | Continuous on soil through the rock | 2 - 3<br>4 - 8 | 2 - 3<br>3 - 4 | 19.5<br>1 |
| B – 3 (Caña Dulce) | 9,888,643 | 603.605 | 147.74 | 50 | 107.00 | 35 - 40<br>40 - 45 | Continuous sampling without SPT | | | 39.0<br>1 |
| B – 4 (Pata de Pàjaro) | 9,879,744 | 597.940 | 140.00 | 50 | 100.00 | 35 - 40<br>40 - 45 | – | | | 39.0<br>1 |
| B – 5 (Guajabito) | 9,878,528 | 590.484 | 112.38 | 30 | 91.00 | 25 - 30 | – | | | 29.5<br>1 |
| B – 6 (Mancha Grande) | 9,892,203 | 589.370 | 110.00 | 30 | 88.60 | 20 - 25 | – | | | 26.5<br>1 |

## Table H.2 Rock Classification for Engineering Geology in Japanese Standard

| Rock Class | Charactcristics |
|---|---|
| A | Hard and fresh rocks. Rock-forming mincrals are fresh and not weathered or altered. Joints and cracks are closed tightly , no weathering on their planes. Clear sound id emitted when hammered. |
| B | Hard and fresh rocks. Rock forming mincrals are weathered slightly or parbally altered. Joints and cracks are closed tightly, without weathering. Clear sound is emitted when hammered. |
| CII | Fairly hard and slightly weathered rocks. Rock-forming mincrals, except quartz, are weathered or altered. Tightness of joints and cracks is slightly reduced and each block is apt to be exfoliated along joints and cracks which sometimes contain clay and other materials, stained by limonites. Slightly dull sound is emitted when hammered. |
| CL | Slightly soft and moderately weathered rock. Rock-forming minicrals, except quartz, are weathered or altered. Exfoliation occurs along joint and cracks by hammering. Joints and cracks sometimes contain clay and other materials. Slightly dull sound is emitted when hammered. |
| CM | Soft and weathered rocks. Rock mincrals are weathered. Exfoliation occurs easily along joints and cracks by hammering. Joints and cracks contain clay and other materials. Dull sound is emitted when hammered. |
| D | Very soft, highly weathered, fractured and/or altered rocks. Rockforming mincrals are highly weathered. Joints and cracks are very loose, easily collapse by weak hammering, which contain clay and other materials. Very dull sound is emitted when hammered. |

| Rock Class | Compressive strength (qu kg/cm²) | Modulus of elasticity (ES kg/cm²) | Modulus of deformation (Ed kg/cm²) | Seismic velocity (km/sec) | Poisson's ratio |
|---|---|---|---|---|---|
| A&B | more than 800 | more than 80,000 | more than 50,000 | more than 3.7 | less than 0.2 |
| CII | more than 800 or 800 to 200 or (less than 200) | 80,000 to 40,000 | 50,000 to 20,000 | 3.7 to 3 | 0.2 to 0.3 |
| CM | 800 to 200 or (less than 200) | 40,000 to 15,000 | 20,000 to 5,000 | 3 to 1.5 | 0.2 to 0.3 |
| CL | 400 to 200 or(less than 200) | less than 15,000 | less than 5,000 | less than 1.5 | more than 0.3 |
| D | less than 200 | less than 15,000 | less than 5,000 | less than 1.5 | more than 0.3 |

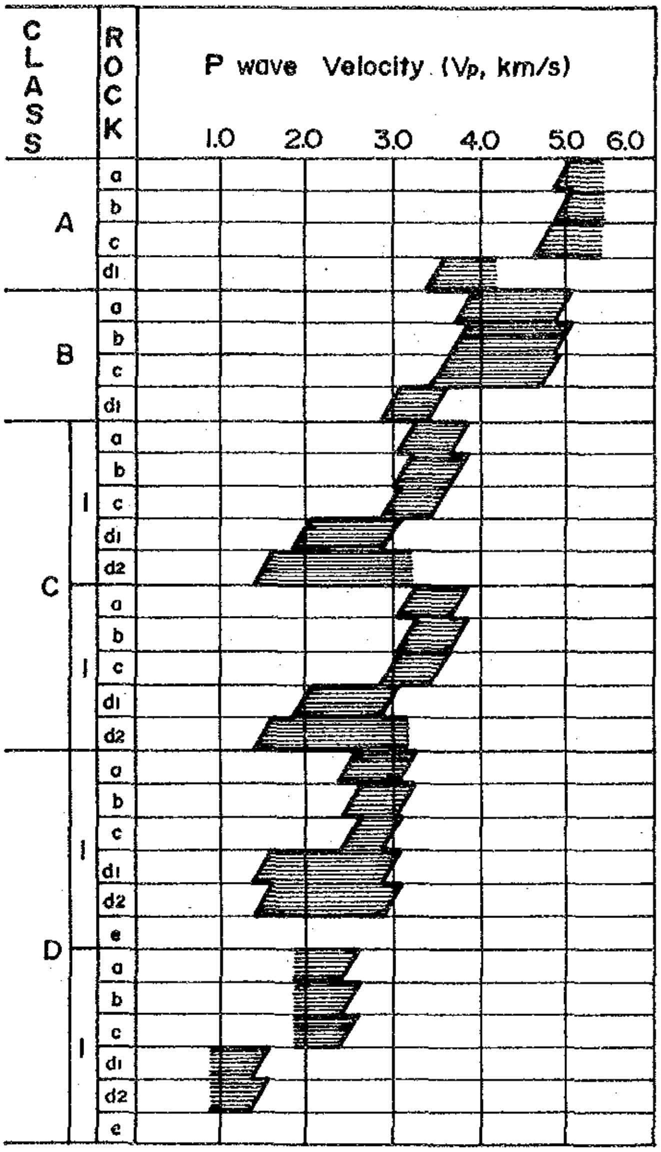
| Rock Class | Cohcsion (kg/cm²) | Intemal friction angle (dcgrcc) | Borchole test: Modulus of deformation (kg/cm²) | Borchole test: Modulus of clasticity Es(kg/cm²) |
|---|---|---|---|---|
| A&B | more than 40 | 55 to 65 | more than 50,000 | more than 100,000 |
| CII | 40 to 20 | 40 to 55 | 60,000 to 15,000 | 150,000 to 60,000 |
| CM | 20 to 10 | 30 to 45 | 20,000 to 3,000 | 60,000 to 10,000 |
| CL&D | less than 10 | 15 to 38 | less than 6,000 | less than 15,000 |

Notcs ;
(1) Compressive strenghth shows the result of rock piece test.
(2) Figures in bracket show the compressive strength for soft rocks.
(3) Modulus of elasticity and defomation show the results of in situ plate loading texis.
(4) Es means sccantial clasticity.

Source ; Standard of Central Rescarch Institute of Electric Power Industry

Table H.3 Rock Classification Based on P wave Velocity Bieniawski"s Rock Classification

## A) Rock Classification Based on P wave Velocity




## B) Bieniawski's Rock Classification

| Rating | 100←81 | 80←61 | 60←41 | 40←21 | <20 |
|---|---|---|---|---|---|
| Class No. | I | II | III | IV | V |
| Description | Very good rock | Good rock | Fair rock | Poor rock | Very poor rock |

MEANIG OF ROCK MASS CLASSES

| Class No. | I | II | III | IV | V |
|---|---|---|---|---|---|
| Average stand up-time | 10 years for 15m span | 6months for 8m span | 1week for 5m span | 10 hours for 2.5m span | 30minutes for 1m span |
| Cohesion of the rook mass | > 400kPa | 300-400kPa | 200-300kPa | 100-200kPa | < 100kPa |
| Friction angle of the rock mass | > 45° | 35°-45° | 25°-35° | 15°-25° | < 15° |

## Table H.4 Contents of Soil Mechanical Test

| Sample № | Location | Sampling Method | Number of Samples | * Item of Soil Test |
|---|---|---|---|---|
| PS(B1) | Pumping Station 0+000 | Shelby, undisturbed | 2 | 1,2,3,4,5,6,7,8,9,10 |
| T(ST) | Head Tank | Disturbed | | 1,2,5,6,7 |
| Si(B2) | Siphon | Shelby, undisturbed | 2 | Ditto |
| C-1 | Channel 0+637 | Test Pit, disturbed and undisturbed | 1 | 1,2,3,4,5,6,7,8,9,11, 12,13,14,15,16,17,18 |
| **C-2 | Channel 1+225 | Ditto | 1 | Ditto |
| C-3 | Channel 1+748 | Ditto | 1 | Ditto |
| C-4 | Channel 2+223 | Ditto | 1 | Ditto |
| C-5 | Channel 2+799 | Ditto | 1 | Ditto |
| C-6 | Channel 3+705 | Ditto | 1 | Ditto |
| **C-7 | Channel 4+422 | Ditto | 1 | Ditto |
| C-8 | Channel 5+336 | Ditto | 1 | Ditto |
| C-9 | Channel 5+881 | Ditto | 1 | Ditto |

| * ITEM OF SOIL TEST | ASTM |
|---|---|
| 1. Unified Soil Classification | |
| 2. Moisture Content Test | D2216 |
| 3. Specific Gravity | D854 |
| 4. Unit Weight (wet & saturated) | ? |
| 5. Particle Size Analysis | D422 D421 |
| 6. Liquid Limit Test | D424 |
| 7. Plastic Limit Test | D423 |
| 8. Unconfined Compression Test | D2166 |
| 9. Triaxial Compression Test (uu) | D2850 |
| 10. Consolidation | D2435 |
| 11. Compaction Test | F1557 |
| 12. Shrinkage Factor Test | D427 |
| 13. Potential Volume | FH A 701 |
| 14. Swelling Test | D4546-85 |
| 15. Pinhole Test for dispersive clays | D4647-87 |
| 16. Laboratory Permeability Test | D2434 |
| 17. Double Hydrometer Test for dispersive clay | AASHTO |
| 18. Chemical Analysis for dispersive clay | T217 |
| ** Test Pit located at crossing streams | T100 |

## Table H.5 Summary of Soil Mechanical Test

| Sample No. | Depth (m) | Geolog & Soil Type | Classificat | Density | | Gs | Wn (%) | Atterberg Limits | | | Shrinkage | | | P.V.C | | Swelling | | Permeability K (cm/sec) | qu $t/m^2$ | Triaxial | | S.P.T. N | Compaction | | Double Hydromet. (Dispers. percent)% | T.Dissolv.Salt | | Pin Hole Test | Consolidation | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $\gamma t$ $t/m^3$ | $\gamma sat$ $t/m^3$ | | | WL % | WP % | IP % | WS % | LS % | VC % | Po $kg/cm^2$ | P.V.C | P ($t/m^2$) | V % | | | C $t/m^2$ | $\phi$ deg | | $\gamma d$ ($t/m^3$) | OMC % | | Na % | TDS meq/1 | | Pp $kg/cm^2$ | Cc | Cv $mm^3/min$ |
| SH.1 | 0.40-0.90 | | ML | | | 2.67 | 33.1 | 46 | 29 | 17 | | | | | | | | - | 4.5 | 8 | 4 | | | | | | | | 0.70 | 0.11 | 2.40-1.60 |
| *PS (B1) | | Co Silt | | | | | | | | | | | | | | | | | | | | 15 | | | | | | - | | | |
| SH.2 | 0.90-1.40 | | MH | | | 2.71 | 29.8 | 59 | 39 | 20 | | | | | | | | - | 4.3 | 5 | 9 | | | | | | | | 0.80 | 0.15 | 4.90-2.50 |
| | 0.55- | | | | | | 23 | 49 | 37 | 12 | | | | | | | | - | - | | | 14 | | | | | | | - | - | - |
| *ST | | 〃 | ML-MH | | | | | | | | | | | | | | | | | | | | | | | | | - | | | |
| | 5.30 | | | | | | 35 | 84 | 46 | 38 | | | | | | | | - | - | | | 34 | | | | | | | - | - | - |
| SH.1 | 0.40-1.00 | | MH | | | 2.72 | 28.1 | 53.3 | 31.1 | 22.2 | | | | | | | | - | - | - | - | | | | | | | | - | - | - |
| *Si (B2) | | 〃 | | | | | | | | | | | | | | | | | | | | 15 | | | | | | - | | | |
| SH.2 | 1.45-2.00 | | MH | | | 2.74 | 31.3 | 53.9 | 35.1 | 18.8 | | | | | | | | - | - | - | - | | | | | | | | - | - | - |
| 1 | 1.80-2.00 | | MH | 1.65 | 1.68 | 2.41 | 42 | 89 | 53 | 36 | 12.1 | 17.0 | 74.8 | 0.82 | 1.8 | 5.4 | 1.31 | 8*10^-6 | 6 | 6 | 10 | | | | 17.6 | 71.6 | 2.488 | ND1 | - | - | - |
| C1 | | Co Clay | | | | | | | | | | | | | | | | | | | | - | | | | | | | | | |
| 2 | 1.00-2.00 | Silt | CH | | | | 32 | 97 | 38 | 59 | | | | | | | | 7.8*10^-7 | | | | | 1.426 | 27.0 | | | | | - | - | - |
| 1 | 1.80-2.00 | | MH | 1.66 | 1.70 | 2.44 | 37 | 75 | 49 | 26 | 15.3 | 11.3 | 43.2 | 2.75 | 7.0 | 15.5 | 4.02 | 3.8*10^-6 | 14 | 6 | 13 | | | | 37.8 | 29.6 | 0.455 | ND1 | - | - | - |
| C2 | | Co Silt | | | | | | | | | | | | | | | | | | | | - | | | | | | | | | |
| 2 | 0.60-2.00 | | MH | | | | 32 | 87 | 39 | 48 | | | | | | | | 4.2*10^-7 | | | | | 1.420 | 28.1 | | | | | - | - | - |
| 1 | 0.75-1.00 | | MH | 1.80 | 1.80 | 2.55 | 37 | 71 | 36 | 35 | 9.8 | 10.8 | 41.0 | 4.35 | >9 | 12.2 | 6.24 | 6.7*10^-6 | 9 | 6 | 5 | | | | 88.7 | 25.4 | 0.599 | ND1 | - | - | - |
| C3 | | 〃 | | | | | | | | | | | | | | | | | | | | - | | | | | | | | | |
| 2 | 0.30-2.00 | | MH | | | | 27 | 87 | 39 | 48 | | | | | | | | 6.0*10^-7 | | | | | 1.434 | 27.6 | | | | | - | - | - |
| 1 | 0.80-1.10 | | MH | 1.64 | 1.64 | 2.36 | 48 | 91 | 48 | 43 | 9.2 | 14.7 | 61.2 | 1.77 | 4.4 | 23.6 | 5.14 | 1.0*10^-6 | 8 | 5 | 0 | | | | 77.9 | 30.8 | 0.635 | ND1 | - | - | - |
| C4 | | 〃 | | | | | | | | | | | | | | | | | | | | - | | | | | | | | | |
| 2 | 0.40-2.00 | | MH | | | | 33 | 86 | 39 | 47 | | | | | | | | 6.2*10^-7 | | | | | 1.382 | 29.2 | | | | | - | - | - |
| 1 | 1.60-1.85 | | MH | 1.64 | 1.67 | 2.46 | 44 | 76 | 53 | 23 | 16.0 | 12.7 | 50.4 | 3.48 | 8.3 | 11.7 | 4.84 | 7.4*10^-7 | 18 | 13 | 0 | | | | 31.2 | 42.2 | 0.773 | ND1 | - | - | - |
| C5 | | Co Clay | | | | | | | | | | | | | | | | | | | | - | | | | | | | | | |
| 2 | 0.40-2.00 | Silt | CH | | | | 37 | 87 | 37 | 50 | | | | | | | | 5.2*10^-7 | | | | | 1.405 | 29.0 | | | | | - | - | - |
| 1 | 1.10-1.30 | | MH | 1.61 | 1.67 | 2.33 | 38 | 87 | 50 | 37 | 13.5 | 11.9 | 46.3 | 3.23 | 5.6 | 23.7 | 6.35 | 7.8*10^-6 | 28 | 11 | 24 | | | | 65.5 | 43.0 | 1.951 | ND1 | - | - | - |
| C6 | | 〃 | | | | | | | | | | | | | | | | | | | | - | | | | | | | | | |
| 2 | 0.70-2.00 | | CH | | | | 30 | 102 | 39 | 63 | | | | | | | | 9.8*10^-7 | | | | | 1.407 | 27.5 | | | | | - | - | - |
| 1 | 1.00-1.25 | | SM | 1.64 | 1.74 | 2.62 | 37 | 46 | 34 | 12 | 25.9 | 6.5 | 22.2 | 0.06 | 0.0 | 1.4 | 0.74 | 5.0*10^-5 | 3 | 6 | 13 | | | | 27.5 | 17.1 | 1.324 | ND1 | - | - | - |
| C7 | | 〃 | | | | | | | | | | | | | | | | | | | | - | | | | | | | | | |
| 2 | 0.20-2.00 | | CH | | | | 25 | 57 | 29 | 28 | | | | | | | | 3.3*10^-5 | | | | | 1.478 | 25.6 | | | | | - | - | - |
| 1 | 1.35-1.60 | | MH | 1.57 | 1.60 | 2.42 | 50 | 69 | 49 | 20 | 22.7 | 9.4 | 34.3 | 2.79 | 7.1 | 9.9 | 2.75 | 5.6*10^-7 | 5 | 3 | 10 | | | | 21.3 | 22.3 | 0.721 | ND1 | - | - | - |
| C8 | | Co Silt | | | | | | | | | | | | | | | | | | | | - | | | | | | | | | |
| 2 | 0.45-2.00 | | MH | | | | 35 | 69 | 36 | 33 | | | | | | | | 1.8*10^-7 | | | | | 1.330 | 31.0 | | | | | - | - | - |
| 1 | 0.85-1.10 | | MH | 1.70 | 1.70 | 2.41 | 43 | 67 | 45 | 22 | 16.0 | 10.5 | 39.7 | 6.43 | >9 | 16.1 | 8.47 | 9.3*10^-7 | 7 | 7 | 17 | | | | 51.2 | 30.2 | 0.963 | ND1 | - | - | - |
| C9 | | 〃 | | | | | | | | | | | | | | | | | | | | - | | | | | | | | | |
| 2 | 0.50-2.00 | | MH | | | | 32 | 81 | 43 | 38 | | | | | | | | 7.6*10^-7 | | | | | 1.274 | 34.7 | | | | | - | - | - |

NOTE:
- *PS(B1) : Pumping Station (Boring No. B1)
- *ST : Head Tank (SPT Test, maximun and minimum values)
- *Si (B2) : Siphon (Boring No. B2)
- SH : Shelby
- 1 : Undisturbed sample
- 2 : Integrated sample
- Co : Colluvial

$\gamma t$ : Density in natural water content. $\gamma sat$ : Density saturated Gs : Specific gravity.
Wn : Natural water content. WL : Liquid limit. WP : Plasticity limit. IP : Index of plasticity.
WS : Shrinkage limit. LS : Linear shrinkage. VC : Volume change. P.V.C : Potencial volume change.
V : Swelling volume change. K : Permeability coefficient. qu : Unconfined compressive strength.
C : Cohesive strength. $\phi$ : Angle of internal friction. $\gamma d$ : Maximum dry density.
OMC : Optimum moisture content.

Po : Equilibrium pressure.
P : Swelling pressure. TDS : Total dissolved salts.
Cc : Compressión index.
Pp : Preconsolidacion pressure.
Cv : Coefficient of consolidation.
ND1 : Nondispersive.

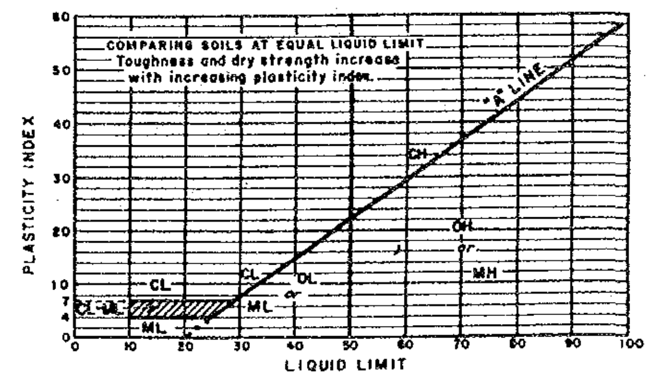
# Table H.6 Unified Soil Classification Chart

## UNIFIED SOIL CLASSIFICATION
### INCLUDING IDENTIFICATION AND DESCRIPTION

| FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3 inches and basing fractions on estimated weights) | | | | GROUP SYMBOLS [1] | TYPICAL NAMES | INFORMATION REQUIRED FOR DESCRIBING SOILS | LABORATORY CLASSIFICATION CRITERIA |
|---|---|---|---|---|---|---|---|
| COARSE GRAINED SOILS More than half of material is <u>larger</u> than No. 200 sieve size [2] (The No. 200 sieve size is about the smallest particle visible to the naked eye) | GRAVELS More than half of coarse fraction is larger than No. 4 sieve size. (For visual classifications, the ¼" size may be used as equivalent to the No. 4 sieve size.) | CLEAN GRAVELS (Little or no fines) | Wide range in grain size and substantial amounts of all intermediate particle sizes. | GW | Well graded gravels, gravel-sand mixtures, little or no fines. | Give typical name; indicate approximate percentages of sand and gravel; max. size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses. | $C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3 |
| | | | Predominantly one size or a range of sizes with some intermediate sizes missing. | GP | Poorly graded gravels, gravel-sand mixtures, little or no fines. | | Not meeting all gradation requirements for GW |
| | | GRAVELS WITH FINES (Appreciable amount of fines) | Non-plastic fines (for identification procedures see ML below). | GM | Silty gravels, poorly graded gravel-sand-silt mixtures. | | Atterberg limits below "A" line, or PI less than 4. Above "A" line with PI between 4 and 7 are <u>borderline</u> cases requiring use of dual symbols. |
| | | | Plastic fines (for identification procedures see CL below). | GC | Clayey gravels, poorly graded gravel-sand-clay mixtures. | For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics. | Atterberg limits above "A" line with PI greater than 7 |
| | SANDS More than half of coarse fraction is smaller than No. 4 sieve size. | CLEAN SANDS (Little or no fines) | Wide range in grain sizes and substantial amounts of all intermediate particle sizes. | SW | Well graded sands, gravelly sands; little or no fines. | | $C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3 |
| | | | Predominantly one size or a range of sizes with some intermediate sizes missing. | SP | Poorly graded sands, gravelly sands; little or no fines. | EXAMPLE:- <u>Silty sand</u>, gravelly; about 20% hard, angular gravel particles ½-in. maximum size; rounded and subangular sand grains coarse to fine; about 15% non-plastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM) | Not meeting all gradation requirements for SW |
| | | SANDS WITH FINES (Appreciable amount of fines) | Non-plastic fines (for identification procedures see ML below). | SM | Silty sands, poorly graded sand-silt mixtures. | | Atterberg limits below "A" line or PI less than 4. Above "A" line with PI between 4 and 7 are <u>borderline</u> cases requiring use of dual symbols. |
| | | | Plastic fines (for identification procedures see CL below). | SC | Clayey sands, poorly graded sand-clay mixtures. | | Atterberg limits above "A" line with PI greater than 7 |

Laboratory classification criteria for coarse grained soils: Use grain size curve in identifying the fractions as given under field identification. Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse grained soils are classified as follows:- Less than 5% GW, GP, SW, SP. More than 12% GM, GC, SM, SC. 5% to 12% <u>Borderline</u> cases requiring use of dual symbols.

| FINE GRAINED SOILS More than half of material is <u>smaller</u> than No. 200 sieve size. | IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN No. 40 SIEVE SIZE: DRY STRENGTH (CRUSHING CHARACTERISTICS) | DILATANCY (REACTION TO SHAKING) | TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT) | GROUP SYMBOLS [1] | TYPICAL NAMES | INFORMATION REQUIRED FOR DESCRIBING SOILS |
|---|---|---|---|---|---|---|
| SILTS AND CLAYS Liquid limit less than 50 | None to slight | Quick to slow | None | ML | Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity. | Give typical name; indicate degree and character of plasticity, amount and maximum size of coarse grains; color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information; and symbol in parentheses. |
| | Medium to high | None to very slow | Medium | CL | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. | |
| | Slight to medium | Slow | Slight | OL | Organic silts and organic silt-clays of low plasticity. | For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions. |
| SILTS AND CLAYS Liquid limit greater than 50 | Slight to medium | Slow to none | Slight to medium | MH | Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts. | |
| | High to very high | None | High | CH | Inorganic clays of high plasticity, fat clays. | EXAMPLE:- <u>Clayey silt</u>, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML) |
| | Medium to high | None to very slow | Slight to medium | OH | Organic clays of medium to high plasticity. | |
| HIGHLY ORGANIC SOILS | Readily identified by color, odor, spongy feel and frequently by fibrous texture. | | | Pt | Peat and other highly organic soils. | |




PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

ADOPTED BY:- CORPS OF ENGINEERS AND BUREAU OF RECLAMATION - JANUARY 1952

[1] <u>Boundary classifications</u>:- Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder.
[2] All sieve sizes on this chart are U.S. standard.

## Table H.7 Criteria for Expansive & Dispersive Soils

A) Shrinkage Factor: Volume Change

| VC: Volume change (%) | Criteria |
|---|---|
| 5 > VC | Good |
| 10 > VC > 5 | Medium |
| 15 > VC > 10 | Bad |
| VC > 15 | Very bad |

B) P.V.C. (Potential Volume Change)

| P.V.C. Value | Criteria |
|---|---|
| < 2 (NC) | Non critical |
| 2 - 4 (M) | Marginal |
| 4 - 6 (VC) | Critical |
| > 6 (VC) | Very critical |

C) Swelling Pressure: P

| P = Swelling pressure (T/m$^2$) | Criteria | V = Volume change (%) |
|---|---|---|
| < 15 | Low | < 1 |
| 15 - 25 | Medium | 1 - 5 |
| 25 - 100 | High | 5 - 10 |
| > 100 | Very high | > 10 |

D) Dispersibility

D1. Double Hydrometer Test

| DI (Dispersive Index) | Criteria |
|---|---|
| DI > 67 | Very unstable |
| 67 > DI > 34 | Medium |
| DI < 34 | Stable |

D2. Soluble Salts in Pore Water (Ca+Mg+Na+k)

| PS = Percent Sodium = $\frac{Na(100)}{Ca+Mg+Na+k}$ | Criteria |
|---|---|
| PS < 40 | Nondispersive |
| 60 > PS > 40 | Dispersive-nondispersive |
| Ps > 60 | Dispersive |

D3. Pinhole Test

| Classification | Degree of Dispersion |
|---|---|
| D1 | Very dispersive |
| D2 | Highly dispersive |
| ND4 | Moderately dispersive |
| ND3 | Slightly dispersive |
| ND2 | Very slightly dispersive |
| ND1 | Non dispersive |

# FIGURES

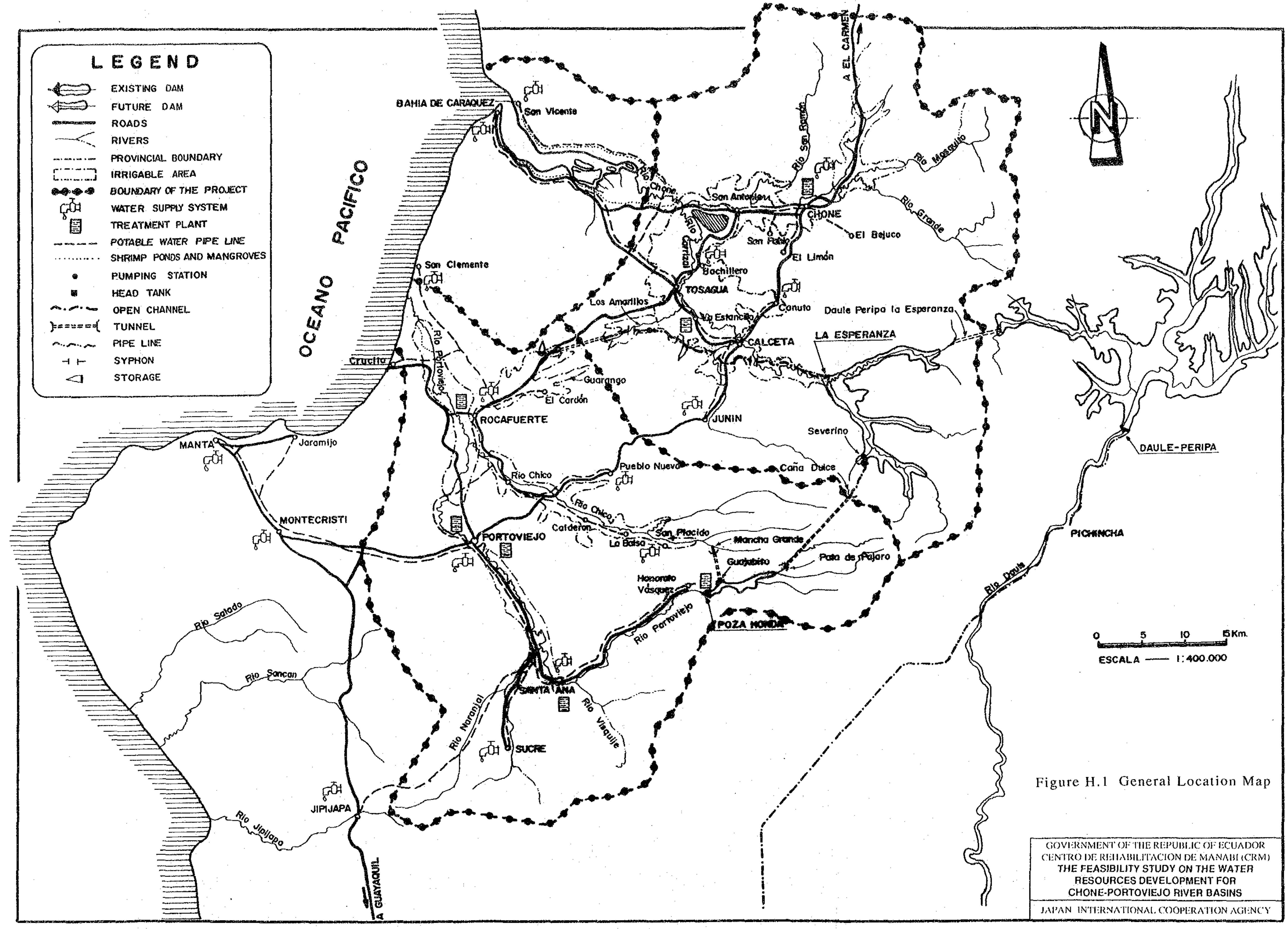



Figure H.1 General Location Map

GOVERNMENT OF THE REPUBLIC OF ECUADOR
CENTRO DE REHABILITACION DE MANABI (CRM)
THE FEASIBILITY STUDY ON THE WATER RESOURCES DEVELOPMENT FOR CHONE-PORTOVIEJO RIVER BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY


Figure H.2 General Geological Plan in the Project Area

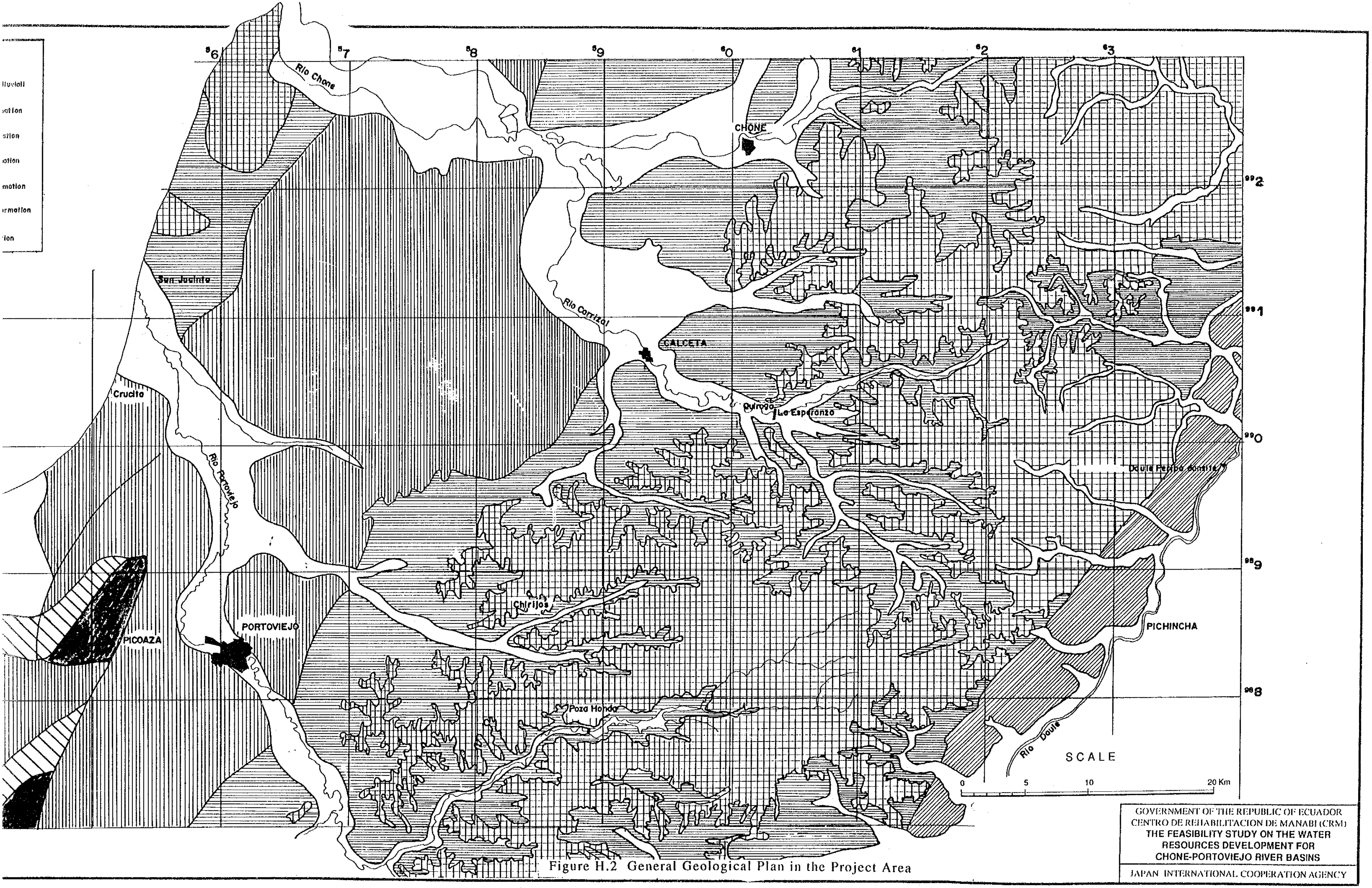



Figure H.2 General Geological Plan in the Project Area

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CENTRO DE REHABILITACION DE MANABI (CRM)
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JAPAN INTERNATIONAL COOPERATION AGENCY

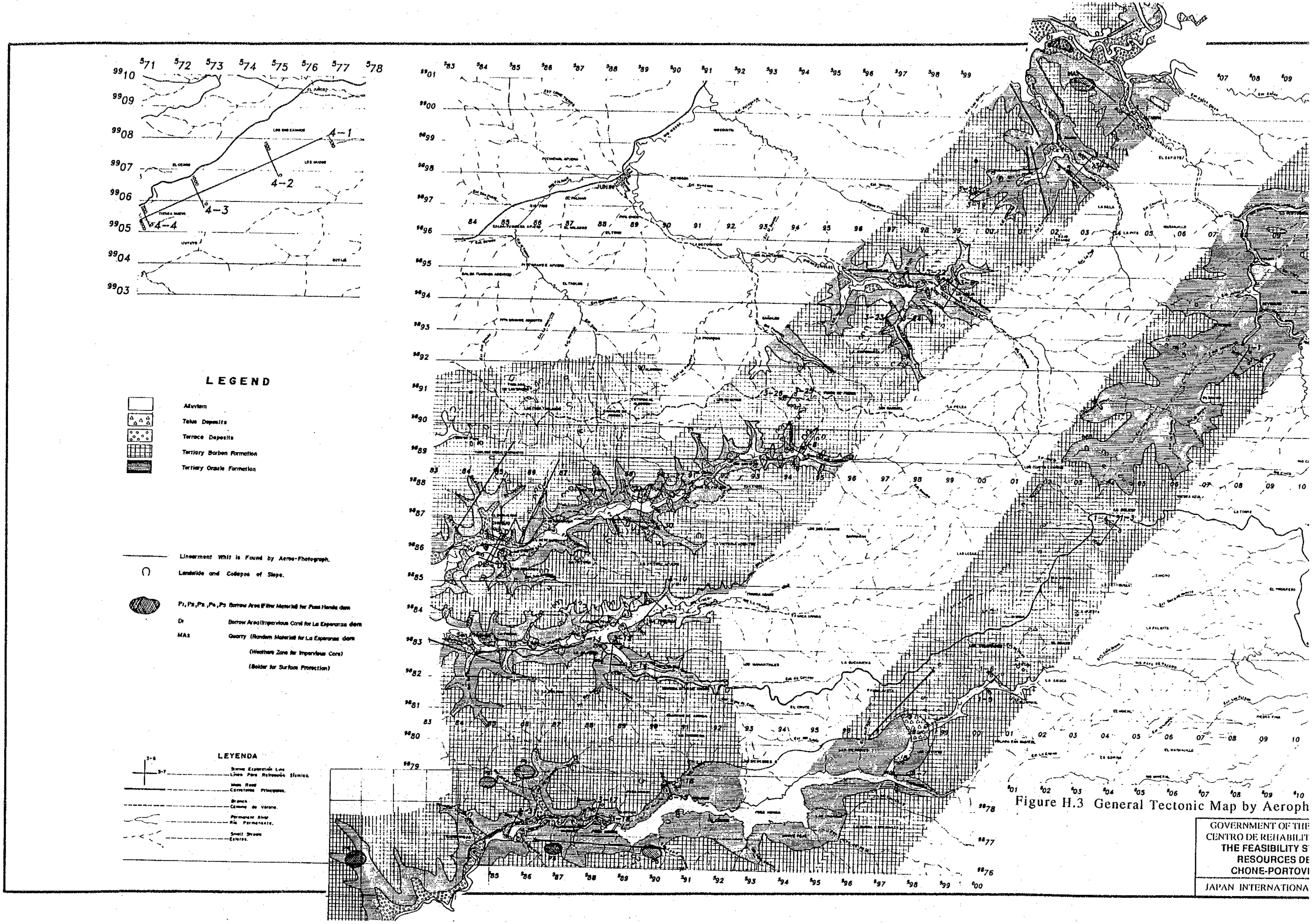


Figure H.3 General Tectonic Map by Aeroph

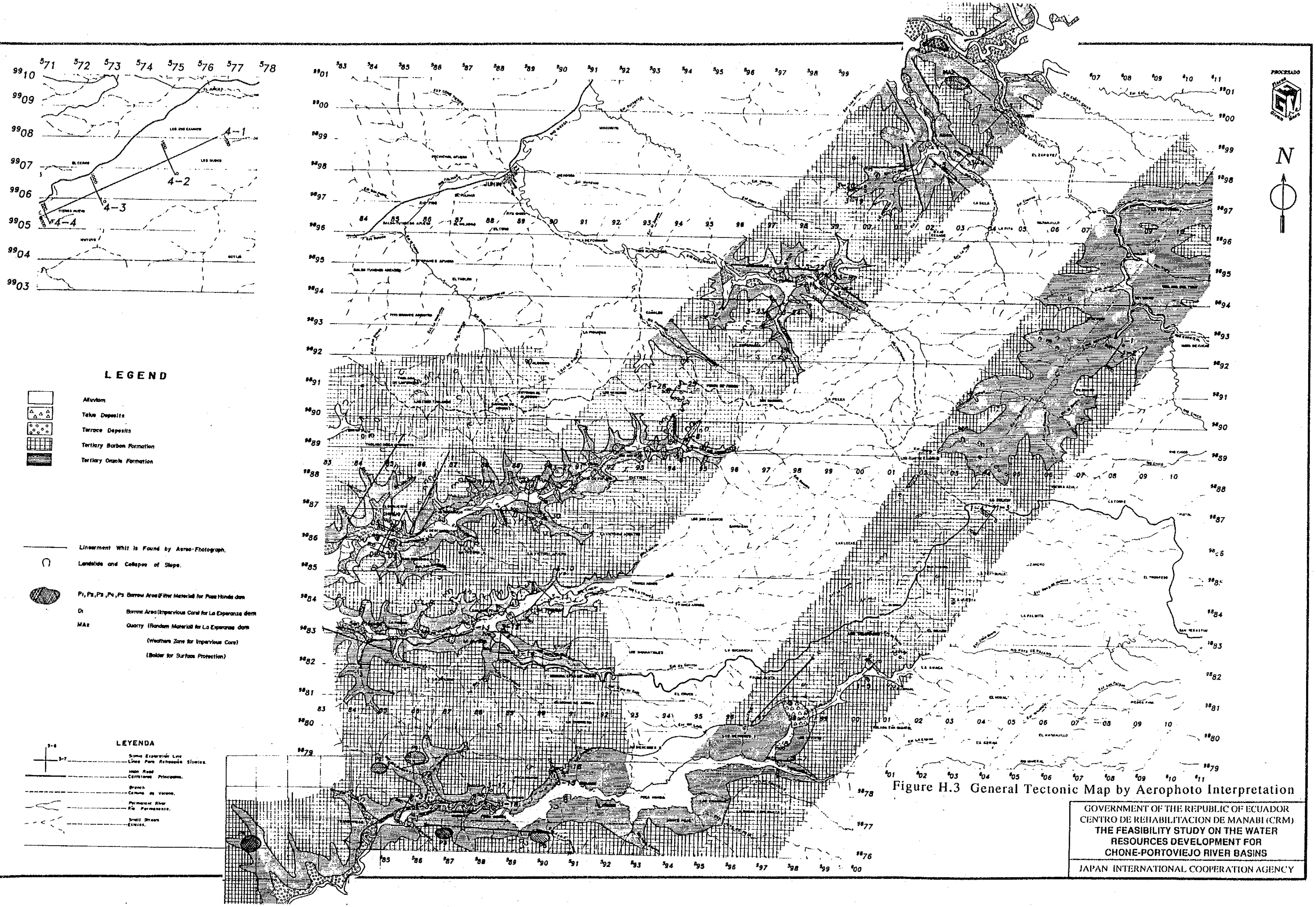


Figure H.3 General Tectonic Map by Aerophoto Interpretation

GOVERNMENT OF THE REPUBLIC OF ECUADOR
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THE FEASIBILITY STUDY ON THE WATER RESOURCES DEVELOPMENT FOR CHONE-PORTOVIEJO RIVER BASINS

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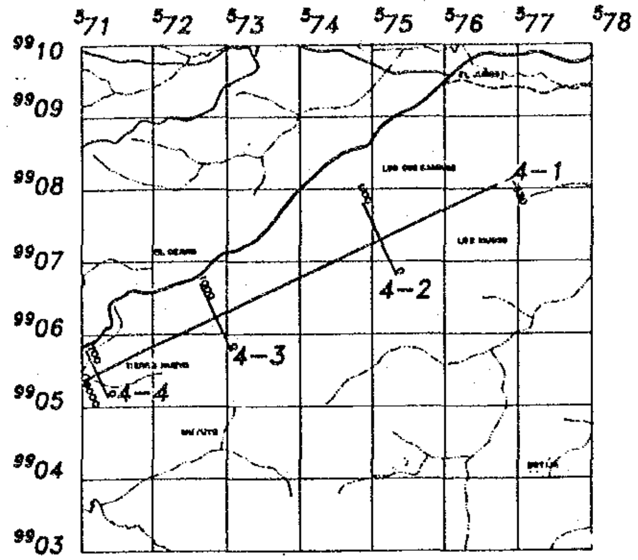


## INDICE

| LINEA | SITIO | LONGITUD (METROS) | AZIMUT (GRADOS) |
|---|---|---|---|
| 3-1 | ALTAMIRA | 1,000 | 42.27 |
| 3-2 | ALTAMIRA | 600 | 132.27 |
| 3-3 | TRUENO | 1,000 | 40.77 |
| 3-4 | TRUENO | 500 | 130.77 |
| 3-5 | TRUENO | 500 | 130.77 |
| 3-6 | ABEJA | 1,000 | 31.24 |
| 3-7 | ABEJA | 500 | 121.24 |
| 3-8 | RONCON | 700 | 28.27 |
| 3-9 | RONCON | 500 | 118.27 |
| 3-10 | SAN PLACIDO (CANTERA) | 1,860 | 39.77 |
| 3-11 | SAN PLACIDO (CANTERA) | 500 | 129.77 |
| 3-12 | SAN PLACIDO | 1,000 | 4.27 |
| 3-13 | SAN PLACIDO | 700 | 94.27 |
| 3-14 | SAN PLACIDO | 800 | 94.27 |
| 3-15 | GUAJABE | 460 | 155.77 |
| 3-16 | GUAJABE | 390 | 245.77 |
| 3-17 | POZA HONDA | 500 | 16.57 |
| 3-18 | POZA HONDA | 500 | 106.57 |
| 3-19 | LA PAVITA | 570 | 52.27 |
| 3-20 | LA PAVITA | 400 | 97.27 |
| 3-21 | ANDARIELES | 300 | 54.02 |
| 3-22 | ANDARIELES | 500 | 144.02 |
| 3-23 | ASTILLERO | 650 | 59.69 |
| 3-24 | ASTILLERO | 500 | 149.69 |
| 3-25 | PUNTA DE PIEDRA (PALMAS) | 400 | 30.27 |
| 3-26 | PUNTA DE PIEDRA (PALMAS) | 500 | 94.60 |
| 3-27 | PAJUY | 1,000 | 29.88 |
| 3-28 | PAJUY | 500 | 119.88 |
| 3-29 | PAJUY | 1,100 | 4.27 |
| 3-30 | PAJUY | 900 | 94.27 |
| 3-31 | HONORATO VASQUEZ | 600 | 26.77 |
| 3-32 | HONORATO VASQUEZ | 380 | 116.77 |
| 1-1 | SEVERINO | 900 | 34.27 |
| 1-2 | SEVERINO | 500 | 124.27 |
| 1-3 | LA DELICIAS | 1,100 | 34.27 |
| 1-4 | LA DELICIAS | 500 | 124.27 |
| 1-5 | RIO PATA DE PAJARO (COLORADO) | 680 | 45.77 |
| 1-6 | RIO PATA DE PAJARO (COLORADO) | 520 | 135.77 |
| 1-7 | RIO MINERAL (POZA HONDA) | 660 | 90.27 |
| 1-8 | RIO MINERAL (POZA HONDA) | 500 | 180.27 |
| 4-1 | GUARANGO | 6,530 | 64.77 |
| 4-2 | GUARANGO | 1,100 | 154.77 |
| 4-3 | GUARANGO | 1,000 | 154.77 |
| 4-4 | GUARANGO | 700 | 154.77 |
| D1 | CHIRIJO | 1,000 | 21.97 |
| D2 | CHIRIJO | 1,000 | 26.29 |
| D3 | CHIRIJO | 600 | 111.97 |
| D4 | CHIRIJO | 600 | 111.97 |
| D5 | CHIRIJO | 600 | 111.97 |

## LEYENDA

Sismic Exploration Line – Linea Para Refracción Sismica
Main Road – Carreteras Principales
Branch – Camino de Verano
Permanent River – Río Permanente
Small Stream – Esteros

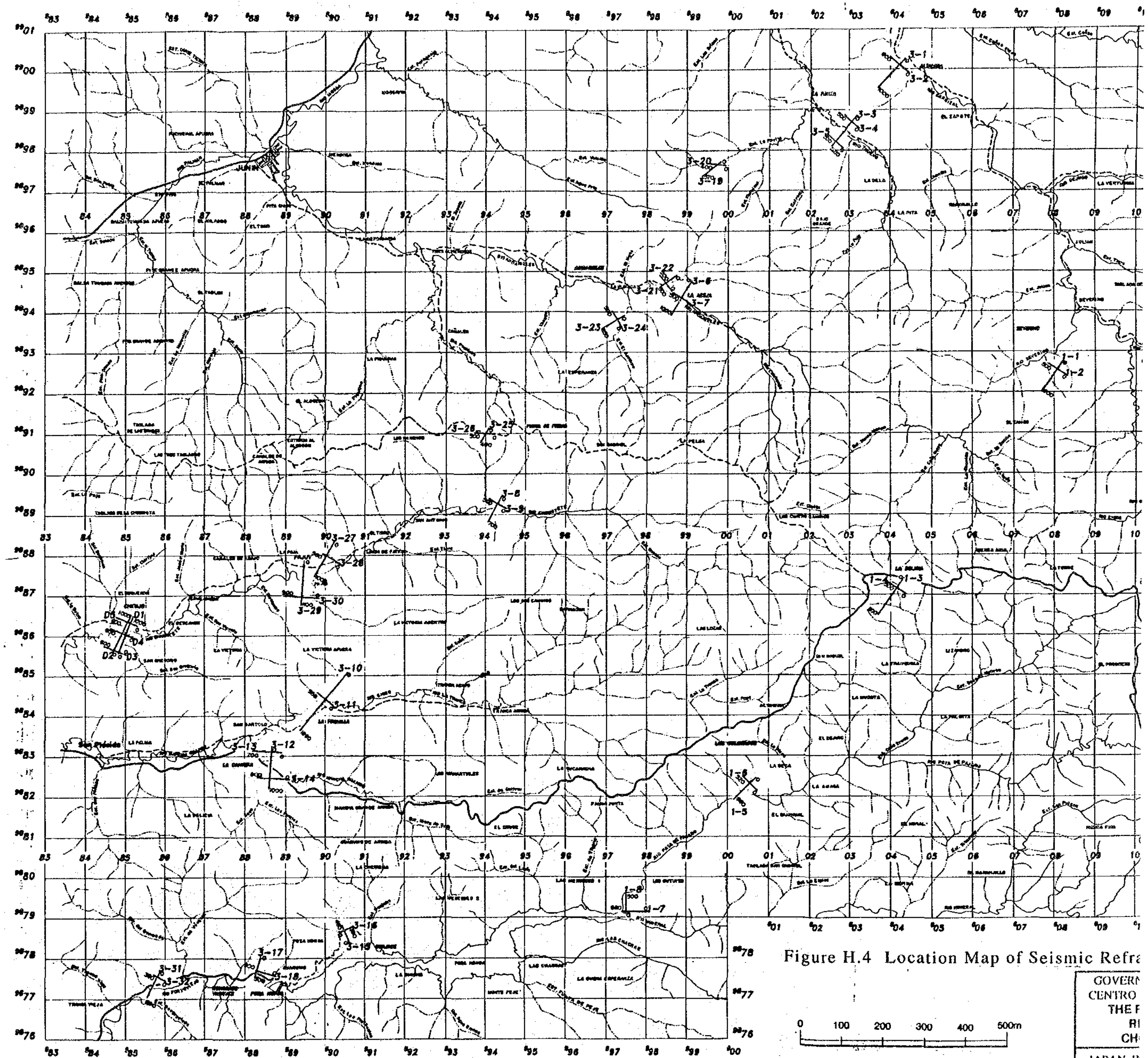


Figure H.4 Location Map of Seismic Refra

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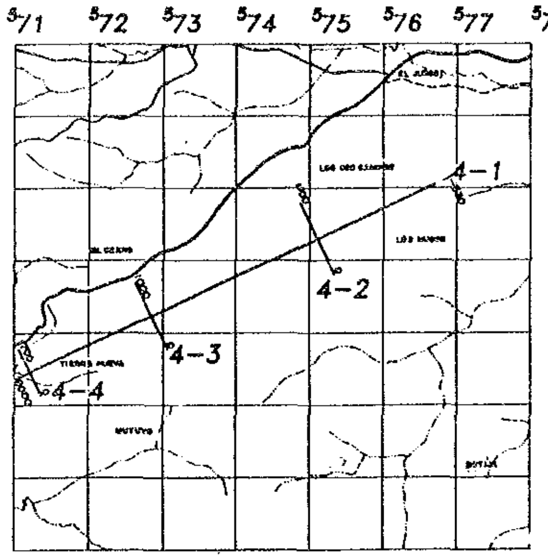

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| 3 - 6 | ABEJA | 1,000 | 31.24 |
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| 3 - 14 | SAN PLACIDO | 800 | 94.27 |
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| 3 - 24 | ASTILLERO | 500 | 149.69 |
| 3 - 25 | PUNTA DE PIEDRA (PALMAS) | 400 | 30.27 |
| 3 - 26 | PUNTA DE PIEDRA (PALMAS) | 500 | 94.60 |
| 3 - 27 | PAJUY | 1,000 | 29.88 |
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| 1 - 6 | RIO PITA DE PAJARO (COLORADO) | 520 | 135.77 |
| 1 - 7 | RIO MINERAL (POZA HONDA) | 660 | 90.27 |
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| D3 | CHIRIJO | 600 | 111.97 |
| D4 | CHIRIJO | 600 | 111.97 |
| D5 | CHIRIJO | 600 | 111.97 |

## LEYENDA

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Main Road — Carretera Principales.
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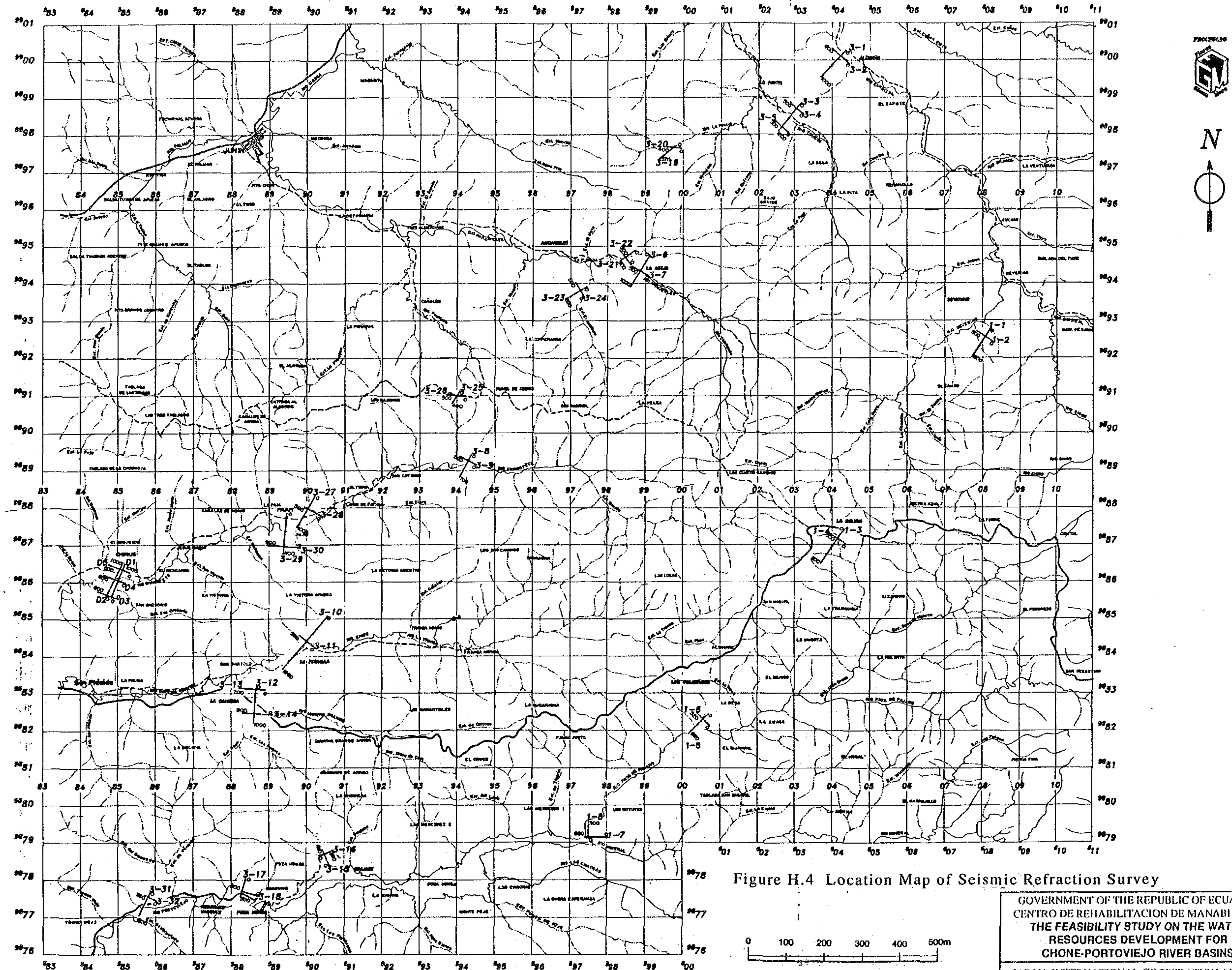

Figure H.4 Location Map of Seismic Refraction Survey

GOVERNMENT OF THE REPUBLIC OF ECUADOR
CENTRO DE REHABILITACION DE MANABI (CRM)
**THE FEASIBILITY STUDY ON THE WATER RESOURCES DEVELOPMENT FOR CHONE-PORTOVIEJO RIVER BASINS**

JAPAN INTERNATIONAL COOPERATION AGENCY

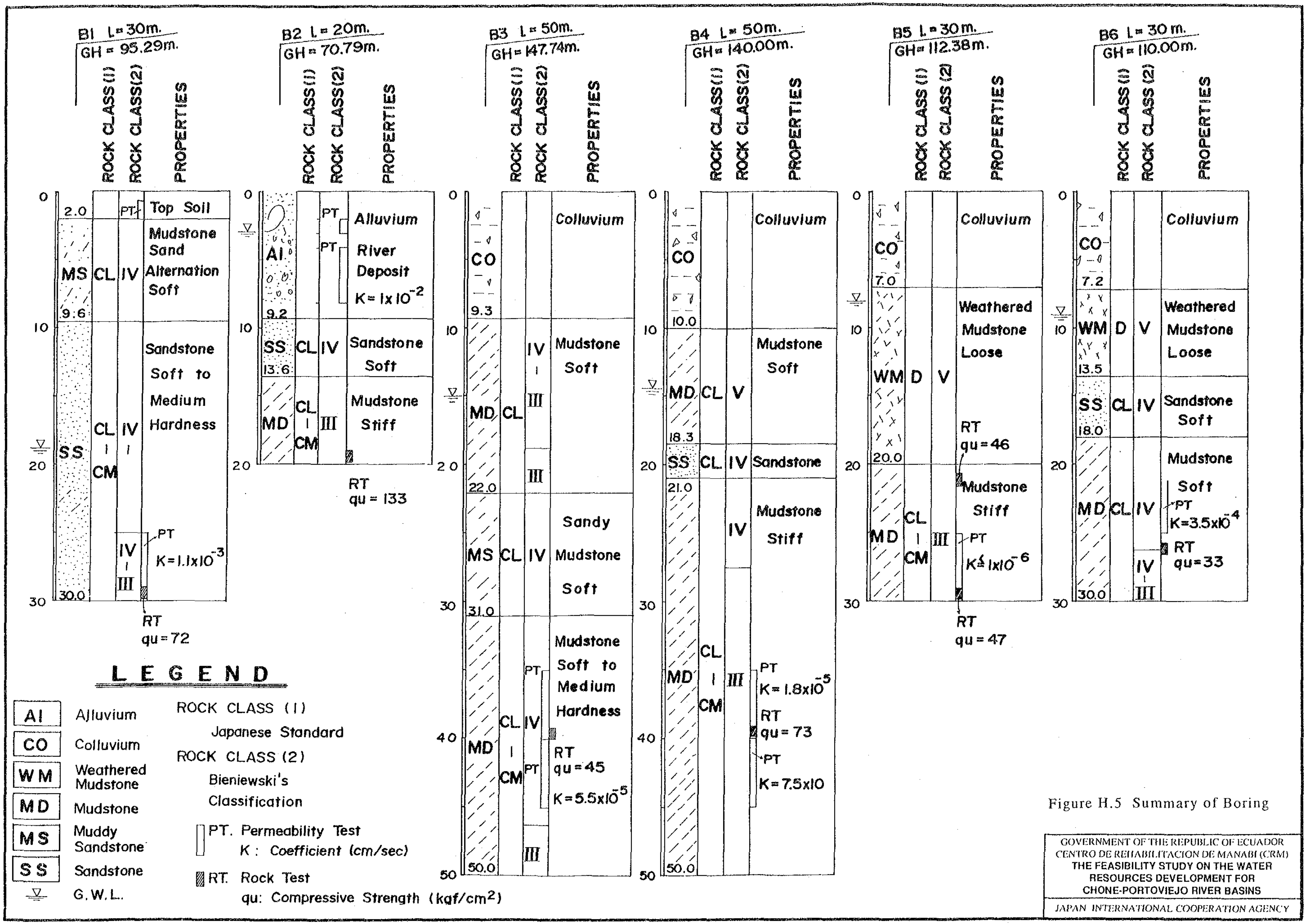


Figure H.5 Summary of Boring