REPUBLIC OF GUATEMALA

REPORT ON

GEOTHERMAL POWER DEVELOPMENT PROJECT

OCT. 1977

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

The Government of Japan in response to the request of the Government of the Republic of Guatemala, has decided to conduct the survey for the geothermal power development project, which has the priority for development of the energy resources of the Republic of Guatemala, and entrusted its implementation to the Japan International Cooperation Agency.

The results of the surveys conducted by the first (1973) and the second (1974) Survey Team in Zunil area, located about 8km southeast of Quezaltenango City, gave strong indication of an existence of a geothermal manifestations and it has been recognized as one of the highest potential area for the geothermal electric power generation.

The third Survey Team further conducted the geological survey, electrical as well as seismic explorations to compile the basic information regarding the geothermal reservoir formation to predict and evaluate the possibilities for economic development of the geothermal electric power generation in Zunil area and to locate the position of the test drill well for the next phase.

The Japan International Cooperation Agency has formed a survey team of ten geoscientists with Mr. Ken-ichi Watanabe of BISHIMETAL EXPLORATION CO. as a team leader and has sent the team to Zunil Area for 55 days from November 29, 1976 to January 21, 1977.

This report is the compilation of the survey results by analyzing the various observation data, and analytical examination of the rock samples, altered minerals, hot-spring water collected at Zunil area.

It is our earnest desire that this report will contribute to the Republic of Guatemala for the geothermal electric power development as well as to contribute to the promotion of economic exchange for the mutual benefit.

In closing, I wish to express my heartfelt gratitude to the investigation team members for their effort, the Government official of the Republic of Guatemala, Officials of the Japanese Embassy in Guatemala for their kind cooperation, and the Ministry of Foreign Affairs and the Ministry of International Trade and Industry for their support in dispatching the investigation team.

August, 1977

Shinsaku Hogen
President
Japan International Cooperation
Agency

LETTER OF TRANSMITTAL

Mr. Shinsaku Hogen
President
Japan International Cooperation Agency

Dear Sir:

Submitted herewith is a report on the Geothermal Power Generation Project Survey (The third survey) of Zunil Area in the Republic of Guatemala.

This third survey is a continuation of the survey, following the two previous survey of the first (1973) and the second (1974), and it was conducted at Zunil area for 55 days from November 28, 1976 to January 21, 1977 with the kind cooperation of Instituto Nacional de Electrificacion (I.N.D.E.) of the Republic of Guatemala in order to analyze the geothermal reservoir formation and to select the location of the test well by conducting the geological survey, electrical as well as seismic explorations.

The survey team, after returning to Japan, analyzed the various survey data and conducted analytical examinations of the informations in combination with two previous survey reports to arrive at a conclusion that the Zunil area is a highly promising area for geothermal energy source with a great potential for the geothermal power generation plant for the future.

In closing, I wish to express my heartfelt appreciations for the tremendous cooperation rendered our Survey team by I.N.D.E. as well as the agencies of the Government of the Republic of Guatemala, the Japanese Embassy in the Republic of Guatemala, and the support given by the Ministry of Foreign Affairs, the Ministry of International Trade and Industry, and the Japan International Co-operation Agency.

August, 1977

Respectfully yours,

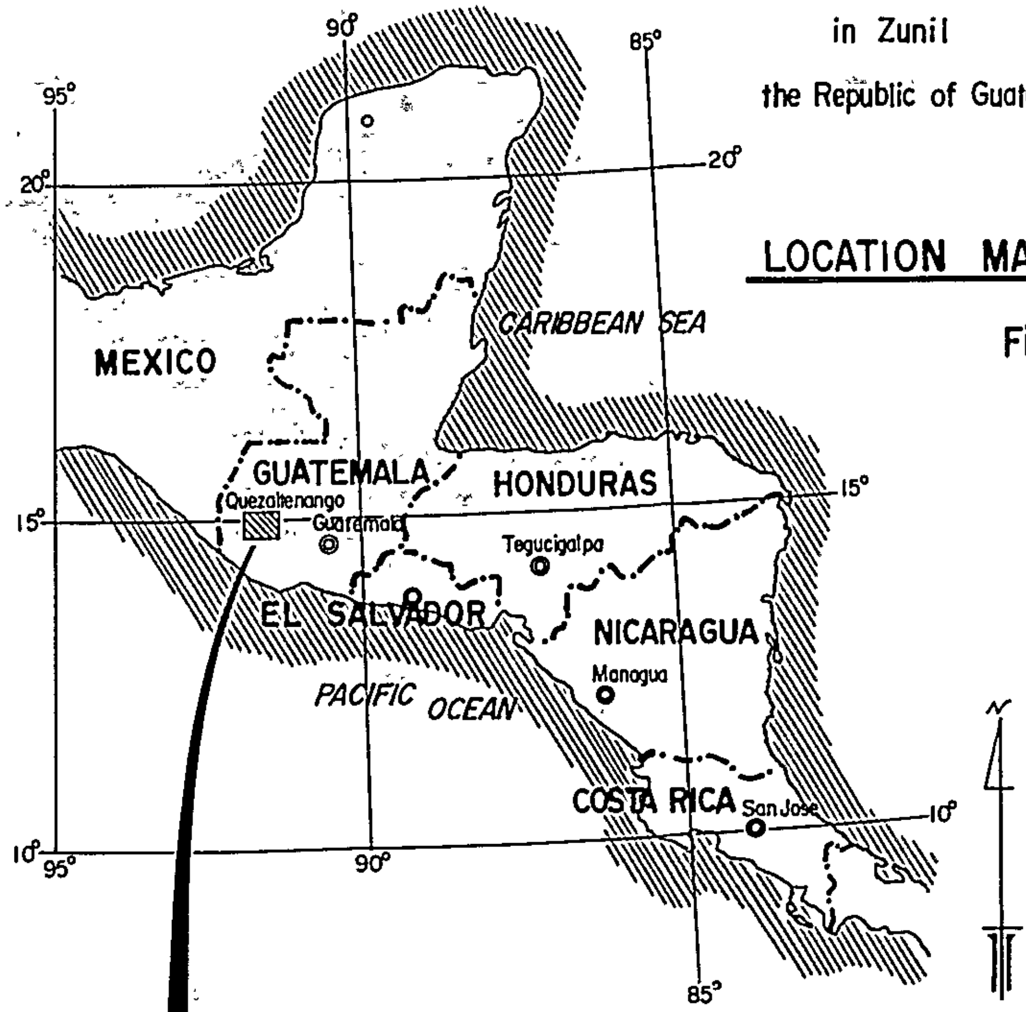
Ken Watanabe

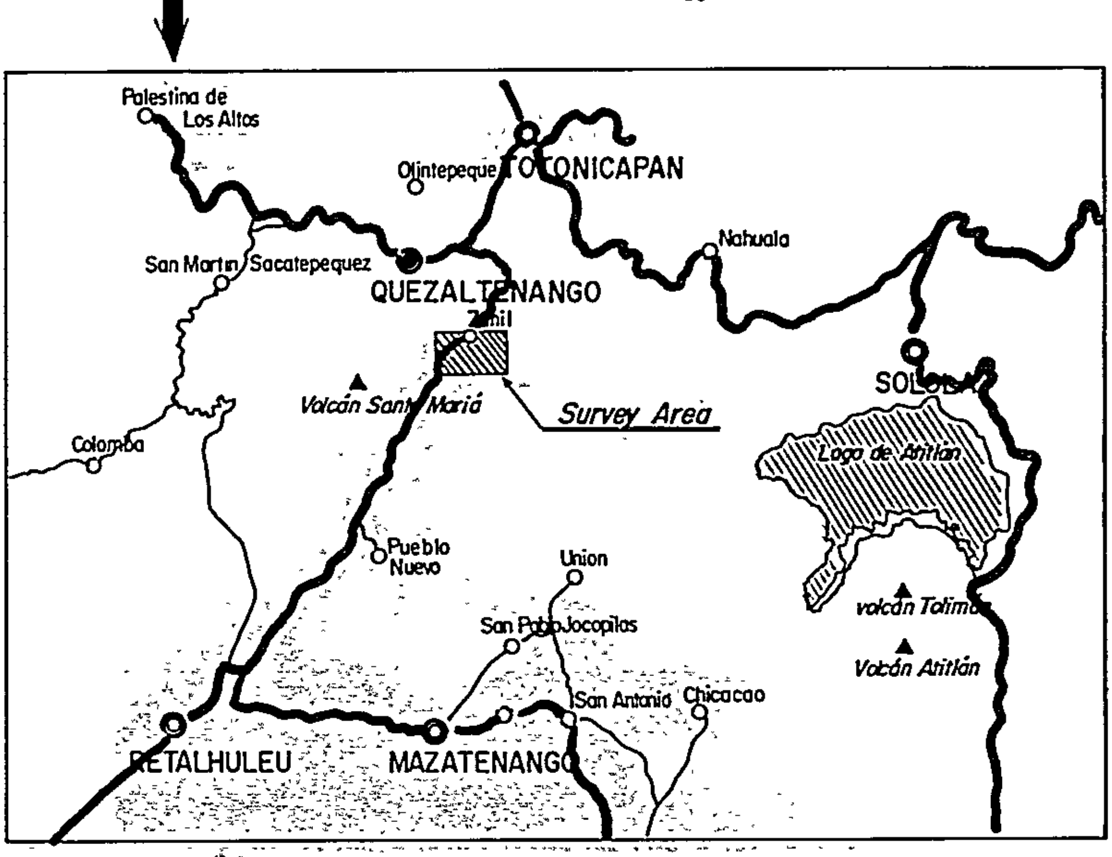
Ken-ichi Watanabe, Leader
Japanese Survey Team
For
Geothermal Power
Development Plan in Zunil

Geothermal Power Development Project
in Zunil
the Republic of Guatemala

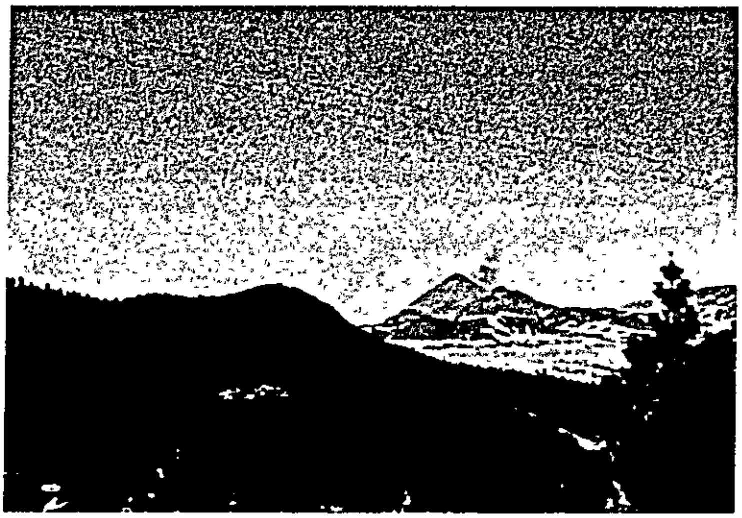
LOCATION MAP

Fig. 1-1

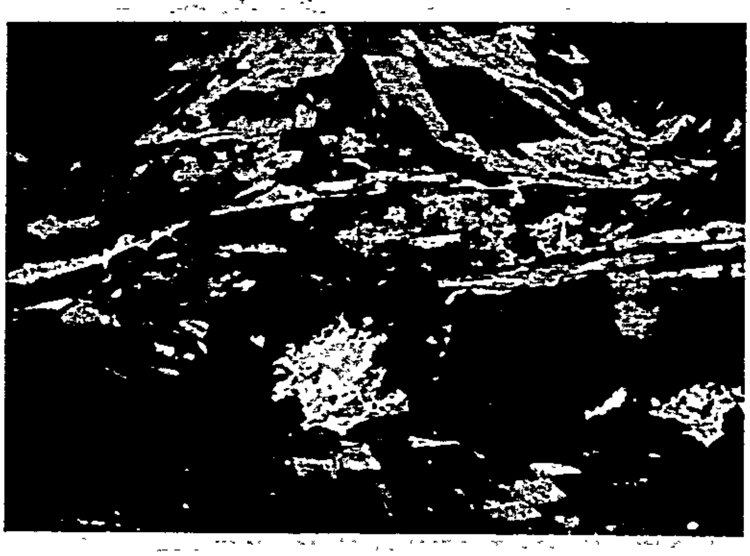




A perspective view of the west side of Zunil area from 2,675m elevation



The eruption of Volcan de Santa Maria



A distant view of Fumarole Negra and Zunil Waterfall

TABLE OF CONTENTS

Table of Contents

(Cont'd)

LIST OF ILLUSTRATIONS AND TABLES

List of Illustrations and Tables

(Cont'd)

List of Illustrations and Tables

(Cont'd)

CHAPTER I

INTRODUCTION

CHAPTER 1

INTRODUCTION

1-1 Objectives of the Survey

The Government of Japan in response to the request of the Government of the Republic of Guatemala has conducted the third geothermal survey by means of the geological, electrical and seismic explorations on the basis of the results obtained from the surveys carried out by the first (1973) and the second (1974) Survey Teams in Zunil area, where the strong geothermal manifestations are expected to exist, in order to verity the geothermal reservoir formation as well as to select the most promising core drill site for the next phase of the survey.

1-2 Details of the Survey

Due to the world wide energy resources problems and the industrialization policy of the Government of Guatemala, the electric power, as the basic resources of the country, is considered to require top priority for development.

The hydroelectric power and the thermal power reinforcement projects are being planned and on the other hand, Guatemala, being a similar volcanic country to Japan, requires urgent development and utilization of the abundant geothermal energy available.

Regarding the geothermal power generation project, the Government of the Republic of Guatemala has requested the Government of Japan for the technical assistance.

Whereas, the Government of Japan in response to the request of Guatemala has assigned the project to the Overseas Technical Cooperation Agency (O. T.C.A.) (which was integrated into the Japan

International Cooperation Agency on August 1, 1974) to be carried out. In turn the Agency has sent the first Survey Team during February - March, 1973 and the second Survey Team during February - March 1974 to the Guatemala site.

From the aforementioned survey results the geology and its structure of the Zunil geothermal area have been secured as a whole.

In the specific area of approximately 2km x 2km, it has been recognized that a strong surface geothermal manifestations are concentrated, and by the geochemical exploration the temperature of the hydrothermal fluid underground is estimated to be very high (temperature of Fumarole Grande 180°C to 210°C).

With the favorable indications obtained, as mentioned above, in order to clarify the various unknown factors the detailed geological and the geophysical explorations should be carried out to conduct feasibility study as well as to evaluate the realization of the geothermal exploration project.

This time the Government of Japan in response to the strong request of the Government of Guatemala has decided to send the third Survey Team and assigned the survey project to the Japan International Cooperation Agency (J.I.C.A.) to be conducted.

1-3 Location and Area of the Survey

The Zunil geothermal area is located adjacent to the Zunil Village covering an area of approximately 7km x 5km, which is about 8km southeast of Quezaltenango City (population approx. 70, 000 and the second largest city in the country), and also it is about 200km west of Guatemala City, the capital.

Through the central part of the survey area the Samala River flows southward through the deep canyon. The elevation of the survey area is approximately 2,000 meter and the climate is divided into two seasons, namely, the raining season being May - October and the dry season being November - April. The average temperature is 15 - 20°C

The road conditions are very well paved and the National Highway runs along side the Samala River in N-S direction. The time required to reach to the side by car is about 4 to 5 hours from Guatemala City and about 30 minutes from Quezaltenango City.

1-4 List of Members

Team Leader	Mr. Ken-ichi Watanabe Bishimetal Exploration Co. (Japan Geothermal Energy Development Center)	
Coordinator	Mr. Masahiro Yamamoto Japan International Cooperation Agency	
Geological survey	Mr. Yasuhiro Kubota Bishimetal Exploration Co.	Chief Geologist
Electrical survey	Mr. Susumu Sasaki Bishimetal Exploration Co.	Chief Geophysicist
do	Mr. Tomio Tanaka Bishimetal Exploration Co.	Geophysicist
do	Mr. Tamio Konno Bishimetal Exploration Co.	Geophysicist
Seismic survey	Mr. Hirosuke Obayashi Bishimetal Exploration Co.	Chief Geophysicist
do	Mr. Hiroshi Fukuda Bishimetal Exploration Co.	Geophysicist

Seismic survey	Mr. Toshimasa Tajima Bishimetal Exploration Co.	Geophysicist
do	Mr. Kaoru Nishida Bishimetal Exploration Co.	Geophysicist

1-5 Itinerary of the Third Survey Team

The survey period of the third Survey Team was total of 55 days from November 28, 1976 to January 21, 1977, and its itinerary was as follows:

Date	Day	Schedule	Remarks
1976 Nov.28	Sun	Tokyo Lv. Los Angeles Ar.	Two members depart as the advance party by PAN 008
29	Mon	Los Angeles Lv. Guatemala Ar.	by PAN 515 A courtesy call on the Japanese Embassy
30	Tue	Guatemala city	Make arrangements with the Japanese Embassy and I.N.D.E. engineers about a visit to Zunil area.
Dec. 1	Wed		A courtesy call on President of I.N.D.E. and a discussion with I.N.D.E. engineers
2) 5	Thu Sun		Preparation for survey in Zunil site
6	Mon		Report to the Japanese Embassy and discussion with I.N.D.E. engineers
7	Tue		Discussion with I.N.D.E. engineers

Date	Day	Schedule	Remarks
Dec. 8	Wed	Tokyo Lv. Mexico City Ar.	The main party of 8 members depart by JAL 012
9	Thu	Mexico City Lv. Guatemala Ar.	by GU 401
10	Fri		A courtesy call on the Japanese Embassy and I.N.D.E.
11	Sat		Discussion with I.N.D.E. engineers in charge
12 } 1977 Jan. 10	Sun Mon		Field Survey Write up the interim reports
11 } 14	Tue Fri		and submittered the reports to the Japanese Embassy as well as I.N.D.E.
15 16	Sat Sun		Survey data studied and arranged and the instruments packed
17	Mon		Interim report of the results of the survey to I.N.D.E.
18	Tue		A courtesy call on the Japanese Embassy and I.N.D.E. for the departure
19	Wed	Guatemala Lv. Los Angeles Ar.	by PAN 516
20	Thu	Los Angeles Lv.	by JAL 061
21	Fri	Tokyo Ar.	Return to Japan

CHAPTER 2

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 2

CONCLUSIONS AND RECOMMENDATIONS

2-1 Conclusions

This area is located in the southern fringe of the Quezaltenango basin, which is in the volcano graben structure closely related to geothermal structure. At the surface many geothermal manifestations are found and the results of various survey indicate that the area has great potential for the geothermal electric power development.

In this survey, as the underground geothermal fluid reservoir may be classified as the stratified aquifer type, the shear zone type or the combination of both types, geological structures were closely studied in order to accomplish our main objective of locating the next drilling site.

In other words, by conducting the geological survey and the seismic exploration the geological and hydrogeological structure concerning the development of faults and fissures, aquifer, surface of unconformity, etc. were clarified. Furthermore, by conducting the electrical survey the distribution of the low resistivity zone, which is closely related to geothermal fluid, were located.

This area is located in the volcanic graben structure running NE-SW with a width of approximately 3km, and eight faults mentioned in the geological survey map as A to H.

These faults are parallel to or intersect at an angle to the main Faults A and D of NE-SW series. In this area between the faults and the neighboring area the fracture zone is highly developed to create channels or reservoir of geothermal fluid for an ideal geothermal district.

Surrounding this area there are volcanoes like Cerro Quemado and Santa Maria, and the geothermal source of this area is considered to be the post volcanic action of Cerro Quemado Volcano.

The geology of the area consists mainly of basement complex of granodiorite covered at unconformity by Old Volcan de Zunil Lava (Tertiary rhyolite), Quarternary lava (andesite) and pyroclastic rocks (pumice tuff, tuff breccia).

In this survey many surface manifestations were found near the faults with compact cap rock and with the low resistivity zone continuing to the depth and the structure similar to anticline or the low velocity zone were confirmed by the seismic survey as the most promising district.

Therefore, the most promising for the geothermal power development areas are summarized as follows:

Area I

Nearby the intersection of Line-1 and Line-3.
The area consists of low resistivity zone of less than 5 Ωm with compact upper structure as a cap rock. Around the Faults Fand D the hot springs and altered zones are distributed.

Area II

In the west of No. 101 and in the area between No. 81 to No. 91 of Line-2, the low resistivity zone are located with less than 5 Ωm accompanied by an anticlinal structure at depth. It is expected that the geothermal fluid exist along the fractured zone of Fault C. The following figures were prepared to summarize the survey.

Fig. 7-1 Survey Planning in Future

Fig. 7-2 Geothermal Exploration Area and Proposed Drilling Site

2-2 Recommendations

From the results of the recent survey completed at the Zunil area, the most promising areas have been selected as mentioned in the foregone chapters.

Therefore, in order to expedite and to realize the geothermal power generation project on the basis of this report by the Government of Guatemala, the following surveys for further study are recommended.

2-2-1 Structural Drilling

By the structural drilling it is necessary to properly confirm the stratigraphy, the temperature gradients and the characteristics of the geothermal fluid reservoir in the promising area.

In conducting the structural drilling all the drill cores should be recovered and the seeping waters at the shallow depths should be sealed off and controlled closely.

A systematic study should be conducted with the typical cores recovered for microscopic study, X-ray diffraction analysis and various physical property studies.

As the same time, the electrical logging (the self-potential and the resistivity), the temperature logging (more than four measurements after mud circulation ceases) and the steam ejection test of the drill hole should also be carried out for the overall evaluation.

2-2-2 Test Hole Drilling

Prior to drilling the production drill holes, the test hole drilling is necessary in order to verify various physical properties and steam ejection conditions at depths.

The test drill holes necessary will be two to three holes with a depth range of 1, 000 to 1, 200 meters.

2-2-3 Reinterpretation

From the results obtained from the drill holes for structure and testing of the geothermal electric power generation the potentials of the survey area should be studied, re-interpreted and re-studied collectively.

Depending on necessity, the supplementary surveys of geological as well as geophysical surveys may be conducted in the survey area.

2-2-4 Regional Survey

As other promising areas may be expected in the surrounding region of the survey area, a regional survey plan should be considered, especially in the northern section. It would be desirable to conduct geological, geophysical and geochemical surveys as well as gravity to study the graben structure, which is closely related to the scale of the geothermal fluid reservoir, on a regional basis to clarify the geothermal structure from all angles.

CHAPTER 3
GEOLOGICAL SURVEY

CHAPTER 3

GEOLOGICAL SURVEY

3-1 Objectives of the Geological Survey

After the first stage preliminary survey, the Zunil area (5 x 7km) was selected for further detailed survey for stratigraphy, geological structure, alteration etc. as well as for further geological survey and also for the geochemistry of the hot springs and hydrogeology in order to obtain the basic information for geothermal power generation project and also to select the anticipated survey drill well location.

3-2 Method of the Geological Survey

3-2-1 Geological Survey

The outcrops of the structural strata were surveyed and plotted on the 1/10, 000 map (especially, the outcrops indicating interrelation and the main sampling points were photographed and recorded) and the geological map of 1/10, 000 and the geological sections were drawn up from the information obtained.

From the collected samples the thin sections were made and microscopic studies conducted and recorded, and for the altered rocks the X-Ray diffraction analysis were also conducted.

The instruments used and the conditions of measurements were as follows:

(1) Microscopic Observation

1) Instruments used

POH made by Nippon Kogaku Kogyo Co., Japan.
Rutomat.(Photography)

2) Method of observation

From the rock samples collected the thin sections were prepared, and the above-mentioned microscopes were used to study the mineral composition, structure, mineral paragenesis, and after clarifying the rock formation and alterations, the microscopic observations were recorded.

Furthermore, the microscopic photographs of the typical part of the samples were taken with Nicol prism at parallel Nicol and cross Nicol.

(2) X-Ray Diffraction

1) Instruments used

X-Ray Diffraction made by Rigaku Denki Co., Japan
Geiger Flex 2034

2) Test procedure

i) The collected samples were ground to 50-100 mesh in a stainless steel mortar. Furthermore, it was ground in the agate mortar until no grit is felt by finger tips to produce non-oriented particles.

ii) X-Ray Diffraction Conditions

Target	Cu
Filter	Ni
Voltage	30
Current	15mV
Counter Type	S.C.
Counter Full Scale	1000cps
Time Constant	1sec.
Scanning Speed	2°/min
Chart Speed	2cm/min

Slits Divergency	1°
Slits Receiving	0.3mm
Slits Scatter	1mm
AI-sample holder	Used

iii) Range of Measurements

2 θ Cuka=3∿40°

3-2-2 Hot Spring Survey

At the point of gushing hot springs, the relation of geology and gushing conditions were recorded as observed. Then the quantity of gushing springs were estimated; temperature and pH were measured and the samples were collected in 500ml polyethylene container. At the same time the hot spring concretions were also sampled. These samples were chemically analyzed after returning to Japan. The instruments used are as follows:

pH meter	DM-1A Type Portable Glass Electorode Meter made by TOA Electronics Ltd., Japan
pH Test Paper	8 types as a set Made by Toyo Kagaku Sangyo Co., Japan

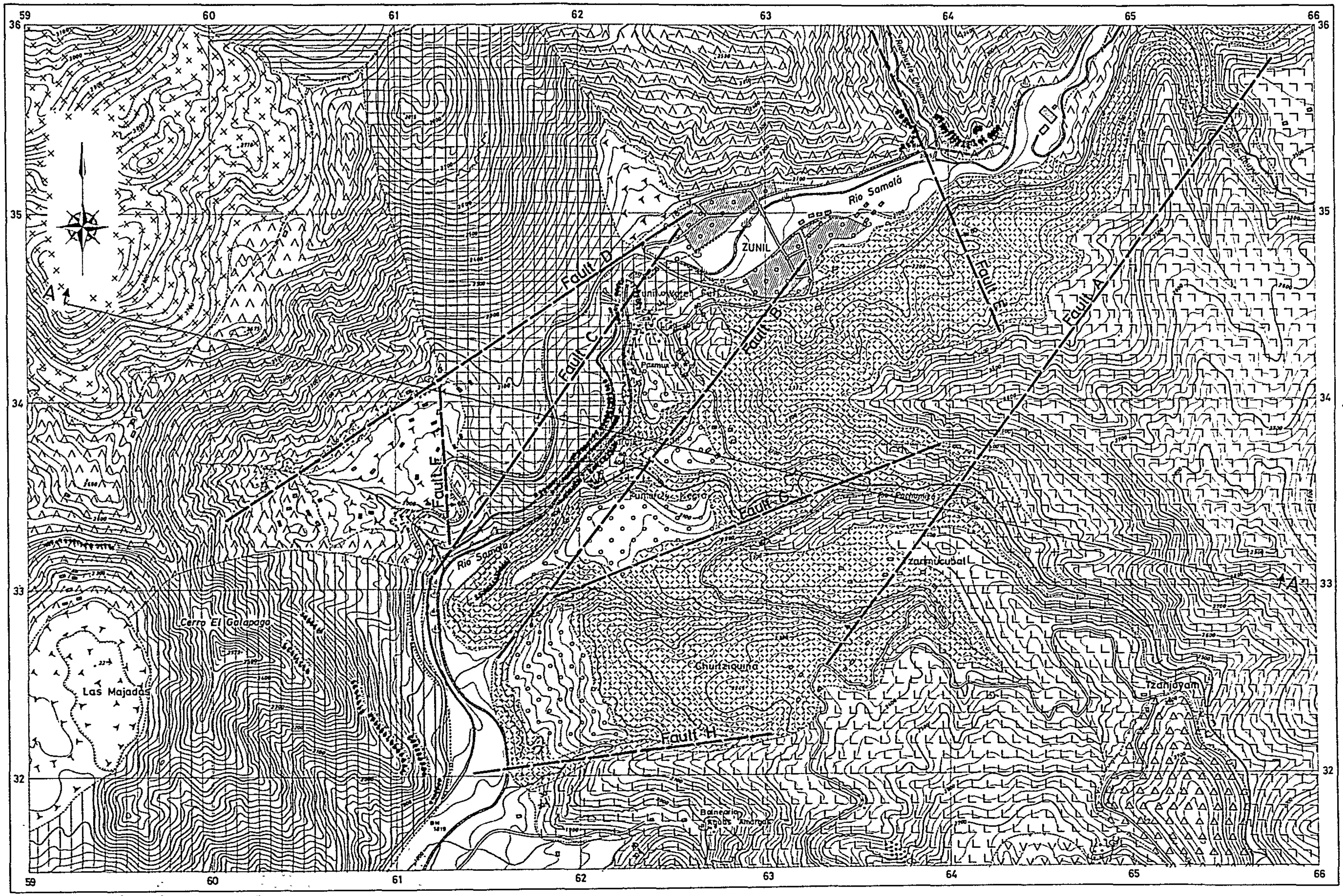
3-3 Geology and Geological Structure

Regarding the naming of the formation, it was based on the First Survey Report, but it was newly established in part and the stratigraphy was partly revised. Geological map, geological sections, and the locations of sampling points are as indicated in Fig. 3-2, 3, 4. The photographic records of the outdoor geography and geology are shown in the photographs PHOTO F-4∿87 and the microscopic photographs are as shown by PHOTO M-1∿21.

Fig. 3-1 Geologic Succession of Zunil Geothermal Field

Geologic Age		Geologic System	Rock Type
Quaternary	Holocene	Alluvial deposits & cone	soil, sand, gravel
		1785 Lava	Bi Ho andesite
		Cerro Quemado Lava	Bi Ho Px andesite
		Zunil Water Fall Lava	Au Hy bg Bi Ho andesite
		Scoria & Pumice deposits	scoria & pumice deposit in air fall
	Pleistocene	Terrace deposits	soil sand grabel
		Zunil formation	andesitic pumiceous tuff, tuff breccia
		Cerro El Galapago Lava	Au Hy Ho andesite
		Almolonga Lava	Hy Au bg Ho andesite
		Volcan de Zunil Lava	Ho Bi Ol Q bg Au Hy andesite
		Tzanjoyam Lava	Bi bg Px dacite
	Tertiary ?	Pachamiya Lava	Ho Au Hy andesite
		Old Volcan de Zunil Lava	Px Ho Bi rhyolite (perlitic)
	Mesozoic	Basement rocks	Bi granodiorite

Px: Pyroxene, Au: augite, Hy: hyperthene, Bi: biotite, Ho: hornblend, Ol: olivine
Q: quartz, bg: bearing



Geologic Age		Geologic System
Quaternary	Holocene	Alluvial Deposits & Cone
		1785 Lavas
		Cerro Quemado Lavas
		Zunil Water-Fall Lavas
	Pleistocene	Scoria Deposits
		Terrace Deposits
		Zunil Formation
		Cerro El Calapago Lavas
		Almolonga Lavas
		Volcan de Zunil Lavas
		Tzanjoyam Lavas
Tertiary		Pachamiya Lavas
		Old Volcan de Zunil Lavas
Mesozoic		Basement Rocks
		Hot Springs
		Fumarole
		Fault
		Altered Zone
		A-A Section Line

Geothermal Power Development Project
Plan in Zunil,
the Republic of Guatemala

GEOLOGICAL MAP

1 : 20,000

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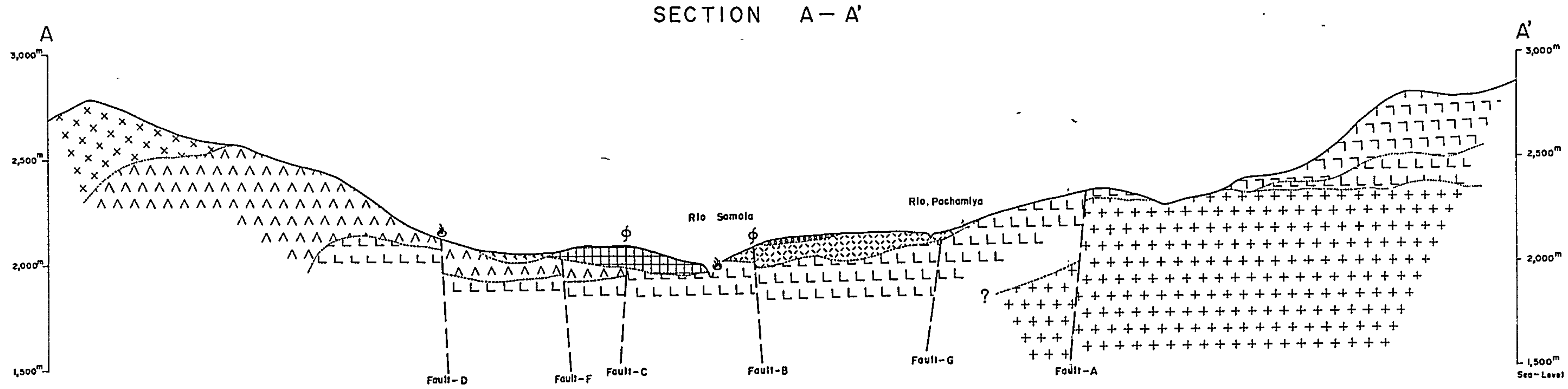
Fig 3-2



LEGEND

- Cerro Quemado Lavas
- Zunil Water-Fall Lavas
- Scoria Deposits
- Terrace Deposits
- Zunil Formation
- Almolonga Lavas
- Pachamiya Lavas
- Old Volcan de Zunil Lavas
- Basement Rocks
- Hot Springs
- Fumarole
- Fault

Geothermal Power Development Project
In Zunil,
the Republic of Guatemala

GEOLOGICAL CROSS SECTION

1 : 20,000

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Fig. 3-3

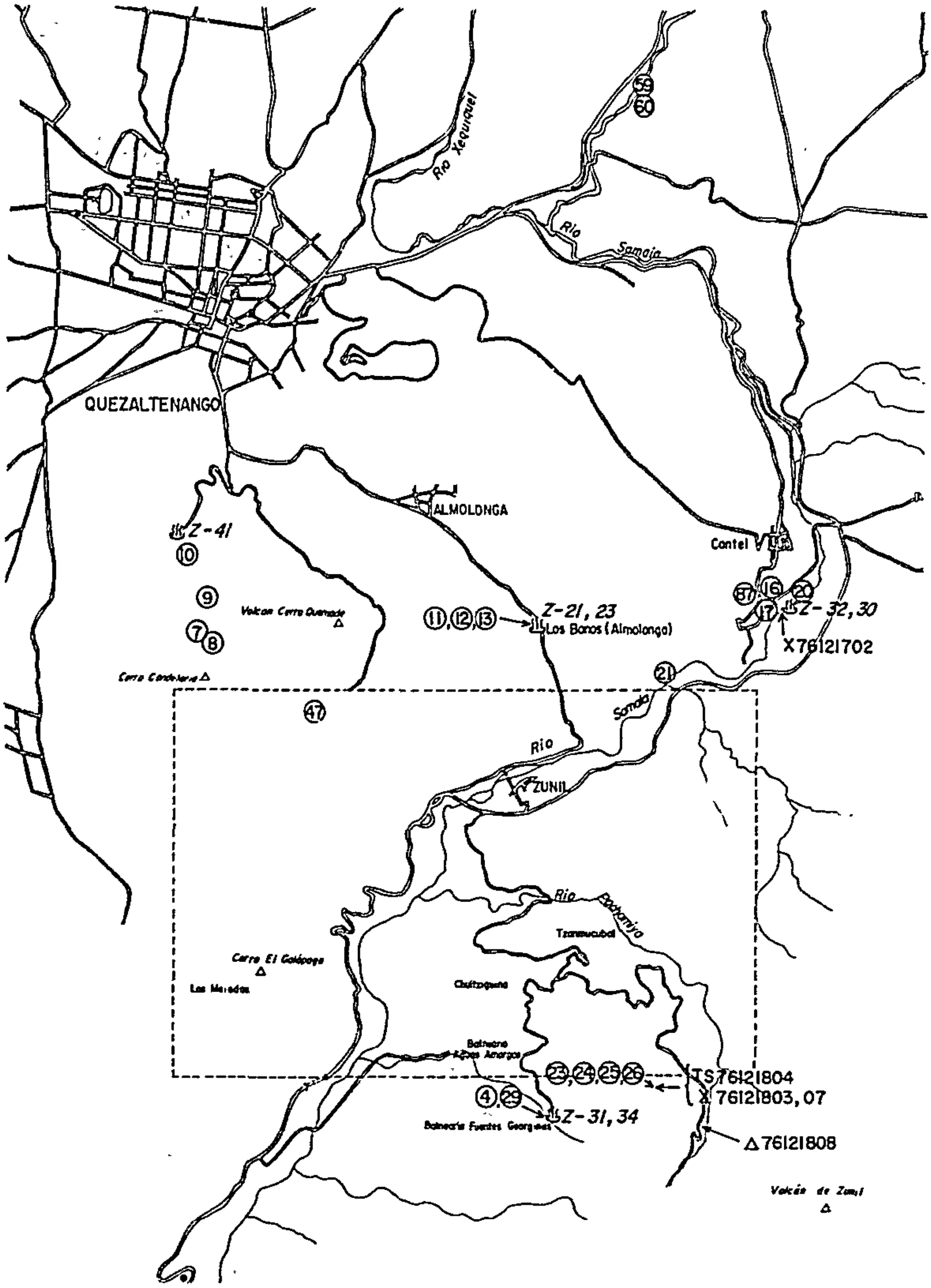
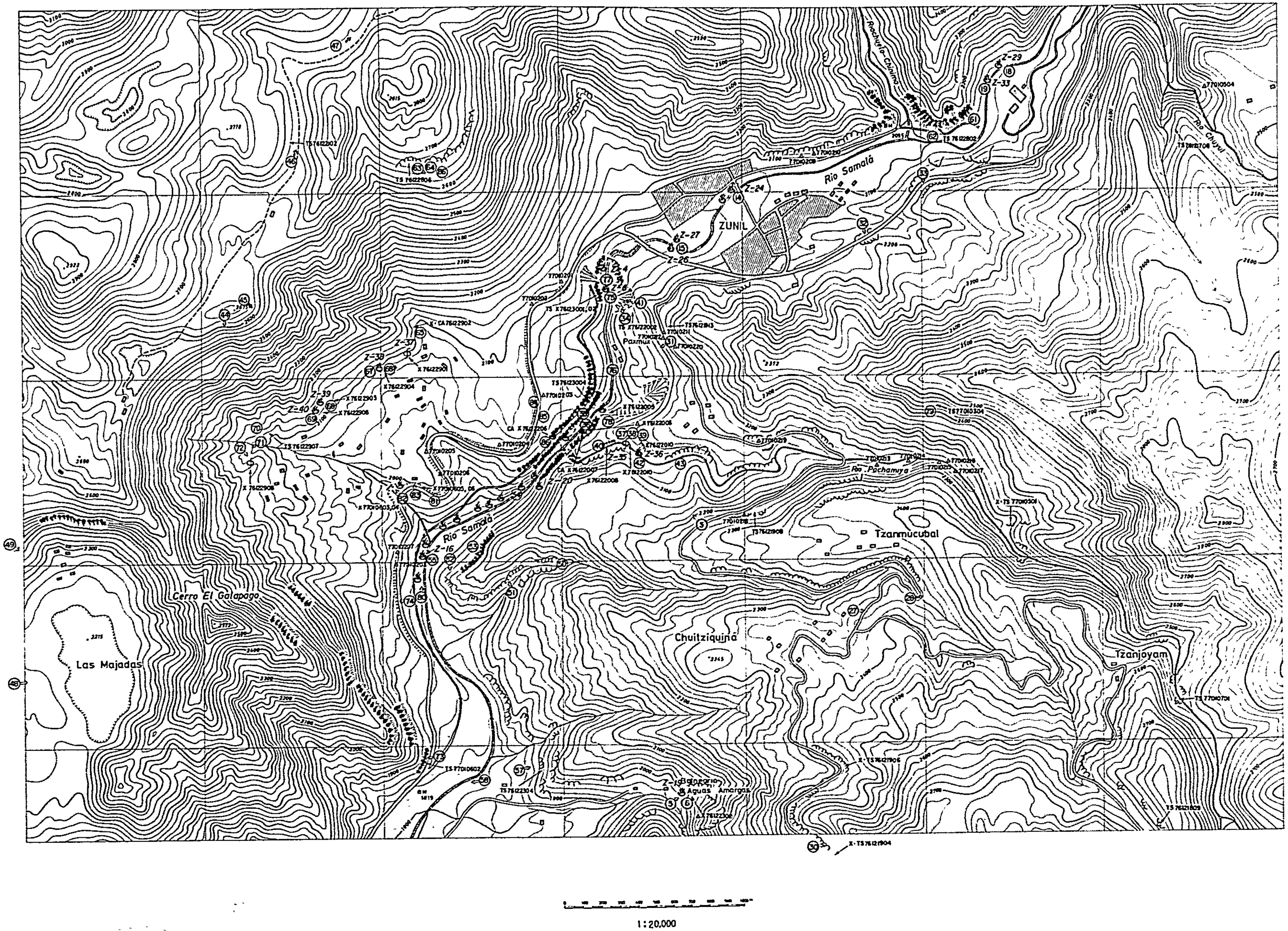


Fig. 3-4-1

Location map of samples and photographs



LEGEND

TS : Sample for thin section
X : Sample for x-ray analysis
CA : Sample for chemical analysis of travertine
Z : Sample for chemical analysis of hot water
○ : No. of photograph
△ : Sample for P wave velocity measurement

Geothermal Power Development Project in Zunil, the Republic of Guatemala

LOCATION MAP OF SAMPLES AND PHOTOGRAPHS

1:20,000

0 — 1,000m

Fig. 3-4-2

3-3-1 The Stratigraphy and Recording Rocks

(1) Basement Complex (Rocks)

It was confirmed that the basement rocks are outcropped at approx. 2,300m elevation at the Chuyul and at the Pachamiya Rivers, respectively.

The outcrops are partly eroded by the present stream but it was observed that the outcrops were compact blocky rocks with little fractures developed.

At the Pachamiya River and at the Chuyul River the basement complex is covered by the Old Volcan de Zunil Lava and the Pachamiya Lava, respectively, at unconformity.

In this area no evidences were found to determine the geological age of granodiorite, but it corresponds to the Cretaceous age according to previous survey (Williams 1960).

Furthermore, the distribution of granodiorite in this area is a new discovery, which was unknown in the past. The basement complex other than granodiorite were not found in the outcrops survey nor in the floating rocks.

(Petrography)

Sample	Sample No. 77010501 Location of the samples collected: At 2,280m elevation along the Pachamiya River.
Photography	PHOTO M-1
Petrology	Biotite granodiorite. Consists of holocrystalline idiomorphic plagioclase crystals of 1.5-2.0mm sizes, xenomorphic quartz, cloudy orthoclase with biotite (Z'=dark brown, X'=yellow) size

maximum 0.7mm, and in general about 0.1-0.3mm.

Besides, it is accompanied by opaque minerals, but no alterations were recognized.

(2) Old Valcan de Zunil Lava

By the first Survey a part of the rhyolitic lava, considered to be the Cerro La Pedrera Lava group, is distributed in the east of the Samala River as well as in the southern area of the Pachamiya River. The color of the lava is from whitish gray to dark gray and some parts brownish gray.

The lava has distinct flow plane structure with rather blocky as well as perlitic facies, and the volcanic breccia to tuff breccia facies are intermixed gradually from one to the other or in alternating strata.

(PHOTO F-4, 5, 30, 40, 52, 54, 57)

The flow planes near Balneario Aguas Amargas are running at NW-SE direction and dip to SW and near Fumarole Negra they run SN with the dip to the west, and near the Zunil Water Fall they run NE-SW and dip to NW.

As the breccia of the lava are found as accidental breccia in the Zunil formation as well as in the breccia strata in the basement of the Pachamiya Lava, that the subject lava should belong below above mentioned two formations. (PHOTO F-16, 43, 79) On the other hand, although the interrelation between the Almolonga Lava and Cerro El Galapago Lava was not observed directly by the outcrops. But, according to the fact that the lava breccia is included in the breccia formation of Cerro El Galapago (PHOTO F-73), and also the degree of dissection of the volcanic geography on the Old Volcan de Zunil Lava is widely distributed (PHOTO F-45), a conclusion has been reached that the Old Volcan de Zunil Lava is located in the lower formation than Cerro El Galapago Lava.

As the lava formation has been confirmed to be distributed outside of the survey area at south of Tzanjoyam village at 2,900m elevation, it may be erupted from the vicinity of Volcan de Zunil.

The lava distributed outside the survey area near Cerro Tecun Uman is unknown whether it is a dome shaped intrusion or not.

The geological age of the lava is unknown, but following Williams (1970) it was decided at the Tertiary. Henceforth, it is necessary to determine the geological age by the fission track method and other means.

(Petrography)

Samples	Sample No. 76121907 Location of sampling: Along the road between Line-3 and 4.
	Sample No. 76121913 Location of sampling: Near the intersection of road at Line-2.
	Sample No. 76122006 Location of sampling: At Fumarole Grande
	Sample No. 76122304 Location of sampling: West of Balneario Aguas Amargas
Photographs	PHOTO M-2, 3, 4, 5

Petrology	Pyroxene hornblende biotite rhyolite
Phenocryst	The idiomorphic plagioclase crystal size as large as 2mm ranging from andesine to oligoclase. Biotite is idiomorphic with maximum size of 0.7mm with Z'=reddish brown to darkish brown, X'=yellowish green to brownish yellow. The hornblende crystal reaches maximum size of 3.0mm, but the majority of crystals ranges from 0.2 to 0.4mm with Z'=brown, X'=yellowish green to yellowish brown. The pyroxene minerals are in small quantities and usually 0.2-0.4mm in size, but at times it reaches 1mm in size. Besides, opaque minerals are accompanied in a small quantity.
Groundmass	Glassy to cryptocrystalline, fine crystals of plagioclase, hornblende and biotite are recognized. The structure is spherlistic with perlitic texture.

(3) Pachamiya Lava

From the survey conducted this time the lava distributed in northern hills of the Pachamiya River was named Pachamiya Lava. The most part of the lava is gray blocky lava, but at the basement the volcanic breccia was recognized.

As the basement formation contains breccia of rhyolite (PHOTO F-79), it should be above the Old Volcan de Zunil Lava. Whereas, in the Zunil Formation the subject lava breccia is included that it should be located below the Zunil Formation.

As the Lava is not distributed in the western part of the Samala River, the stratigraphic relation between the Cerro El Galapago Lava and Almolonga Lava is unknown. The geological age is also unknown, but following Williams (1970), it was decided as Tertiary Age.

In some part of the lava the basaltic rocks with olivine (sample No. 77010701) were recognized, but the details of the distribution is unknown. With the future survey the lava may be classified as a separate lava formation.

(Petrography)

Samples	Sample No. 76121708 Point of sampling: The Chuyul River Sample No. 77010304 Point of sampling: Eastern end of Line-3 Sample No. 77010701 Point of sampling: Eastern part of Tzanjoyam
Photographs	PHOTO M-6, 7, 8
Petrology	Hornblende augite, hypersthene andesite.
Phenocryst	The idiomorphic plagioclase with crystals of max. 1.5mm and normally 0.3-0.7mm with inclusions and often times with worm-eaten pattern. The hypersthene and augite are idiomorphic with the crystal sizes of about 0.2-0.5mm. The hornblende ranges 0.2-0.5mm with Z'= yellowish green, X'=light yellow and often times the crystals with opacitic margine observed, and other opaque minerals are also

found.

Moreover, in the Sample No. 77010701 iddingsited olivine minerals are found.

Groundmass	Consists of glassy, very fine plagioclase and crystallite. In the voids tridymites are recognized and the texture is glassy flow to intersertal.

(4) Tzanjoyam Lava

The lava is distributed in the south eastern part of Tzanjoyam village extending to south east forming the small hills. The lava is somewhat highly porous with brownish grey color.

The geological age and the stratigraphic relations with others are unknown, but from the interpretation of topography the lava is considered to be from the south east along the old river canyon to form the present hills and also it was assumed to be equivalent to the Quaternary, which is the upper strata of Pachamiya Lava.

(Petrography)

Samples	Sample No. 76121809 Sampled at south of Tzanjoyam
Photographs	PHOTO M-9
Petrology	Biotite bearing pyroxene dacite
Phenocryst	The idiomorphic plagioclase in max. 1.5mm in size and the crystal with saussutite rim. The corroded quartz of 1.0mm are observed and augite-hypersthenes of 0.05-0.2mm sizes at times have black rim.

	The biotite has black opacite rim with Z'= brown, X'=light yellow. Some opaque minerals are scattered.
Groundmass	Consist of glassy as well as fine crystallite and the voids are filled with tridymite. The groundmass is hyalopilitic.

(5) Volcan de Zunil Lava

To the east of Balneario Fuentes Georginas the volcanic topography of lava dome is formed (PHOTO F-45). To the south of Tzanjoyam active solfataras are found at elevation of about 2,750 meters (PHOTO F-23, 24, 25).

The correlation with other lavas are unknown, but as the volcanic topography is comparatively well preserved, it is estimated to be the same age as Almolonga Lava.

(Petrography)

Sample	Sample No. 76121804 Location: Near solfatara
Photograph	PHOTO M-10
Petrology	Hornblende biotite olivine quartz bearing pyroxene andesite
Phenocryst	Plagioclase with max. 2.0mm in size with some idiomorphic minerals with other corroded with saussulite rim. The quartz is about 0.7mm in size corroded with xenomorphic crystals. The hypersthene and augite minerals ranges 0.2-0.5mm with idiomorphic crystals. The olivine are colorless with size of 0.5-0.6mm. The biotite ranges

	from 0.3-0.7mm and often the crystals with opacitic rim Z'=reddish brown, X'=yellowish green. The hornblende is 0.2mm in size and crystal rims are opacitic also with Z'=yellowish brown, X'=light yellow. Small amount of opaque minerals are also found.
Groundmass	Consists of glassy and crystallite of plagioclase pyroxene and the voids are filled with tridymite forming an intersertal structure. Moreover, the holocrystalline rocks (granite) are included.

(6) Almolonga Lava

This lava composes the basement rocks of large dome shaped Cerro Quemado volcanic body, which is observed to form practically horizontal columnar joints (PHOTO F-62) that it is considered partly to be an intrusive body.

As the rocks of this lava is included in the Zunil Formation and the Zunil Formation is in contact with the lava at abut structure (PHOTO F-61), the lava should be the lower strata of the Zunil Formation.

The blocky compact gray andesite without biotite is distinctly differentiated from the Zunil Water Fall Lava.

(Petrography)

Samples	Sample No. 76122907 Sampled near western end of Line-3
	Sample No. 76122802 Sampled south-west of hydraulic power plant.

Photographs	PHOTO M-11, 12
Petrology	Augite hypersthene bearing hornblende andesite
Phenocryst	The largest plagioclase idiomorphic crystals are as large as 3.0mm. Hornblende size is max. 1.5mm, but generally idiomorphic crystals of 0.1-0.5mm with edges opacitic, Z'=yellowish brown, X'=light yellowish green with optical characteristics. Augite and hypersthene are about 0.2-0.7mm in small quantity in idiomorphic crystals. Other minerals are small amount of opaque minerals with very rarely biotite recognized.
Groundmass	Consists of glassy and fine plagioclases hornblende, pyroxene, alkali-feldspar with glassy flow texture to intersertal structure.

(7) Cerro El Galapago Lava

The rocks forming the Cerro El Galapago Volcano consist of blocky lava flow and the accessory pyroclastic flow.

This volcano is observed to be a parasitic volcano of Cerro Quemado Volcano with a caldera type crater of about 1km in diameter, where Los Majadas village is located. (PHOTO F-25, 44, 48, 49) Incidentally, at Los Majadas no gushing hot springs were found.

The lava is gray to dark gray and its characteristics is large phenocrysts of pyroxene and hornblende. The geological age is unknown but following the first survey report it was placed above the Almolonga Lava.

(Petrography)

Samples	Sample No. 77010602 Lower stream of the Samala River
Photograph	PHOTO M-13
Petrology	Hypersthene, augite, hornblende andesite
Phenocryst	The largest plagioclase crystals are 2.0mm with normal size of 2.0-0.8mm and idiomorphic crystals being corroded inside in the most of the cases. Pyroxene crystals are max. of 1.2mm with normal size of 0.3-0.4mm with idiomorphic crystals. Hornblende reached max. size of 1.5mm and most of them with opacite rim. Besides, a small amount of opaque minerals were found.
Groundmass	Consists of glassy and ultra fine crystals of plagioclase, pyroxene and voids are filled with tridymite indicating intersertal texture.

(8) Zunil Formation

From the first survey report, it was considered as the lowest bed in this area, and also considered as an equivalent to the Zunil Group formation, which is comparable to the Tertiary. But as it will be explained later, it has been concluded, as being a sedimentary formation of the Quaternary Age.

Probably, it is equivalent to the southern end of the Cantel Formation deposited in the bowl-shaped basin of Quezaltenango.

This formation is distributed mainly along the eastern bank (the left bank) of the Samala River. The upper limits coincide with the contour of 2,300m elevation. The formation is cormposed of alternate strata of pumice-tuff and tuff breccia and above the 2,050m level it is tuffacious and below it is highly developed tuff breccia.

At the outcrops of the granodiorite along the Pachamiya River no distribution of the formation is found and it may have been erroded.

The sorting process is clear and the graded bedding and cross bedding are recognized indicating the sedimentation under water. The surface of sediments are horizontal or slightly inclined to north (PHOTO F-16, 17, 32, 43, 50, 51, 52, 53).

The pumice, as an essential breccia, constitute about 30 to 60% of the formation and as the accidental breccia, dark gray slightly basic andesite (corresponds to Pachamiya Lava, sample No. 77010701), gray pyroxene hornblende andesite (corresponds to Pachamiya Lava, Almolonga Lava, Cerro El Galapago Lava), pyroxene biotite andesite (corresponds to the essential breccia or Tzanjoyam Lava), rhyolite or perlite (corresponds to the Old Volcan de Zunil Lava) and broken granodiorite rocks are included.

Moreover, the outcrops where the Formation abuts with the Old Volcan de Zunil Lava and Almolonga Lava were confirmed. (PHOTO F-52, 61) Near where the abut structure is shown, the rocks from the lower strata (the structure being abutted) are included in the largest quantity in the accidental breccia. On the other hand, the Formation is covered with the conglomerate of terrace type deposit. (PHOTO F-20)

Consequently, the geological age of Zunil Formation is not as old as previously considered. The age is Quaternary and from its nature of distribution, it is probably formed in the bowl structure of Quezaltenango by consecutive sedimentation of the lake origin with about same age as Cantel Formation.

Moverover, it is proper to consider the Formation to be developed more toward the southern region. In the Zunil area from its nature of distribution it is clearly judged that the sedimentation has taken place in the old river canyon along the Samala River.

Furthermore, regarding the problems of the formation as i) hardly any distribution is found on the west bank of the Samala River, ii) about 500m north of Balneario Aguas Amargas the distribution reveals vertical contact with rhyolite, iii) from south of Balneario Aguas Amargas the corresponding formation is not found, will be explained later.

The pumice and andesite considered to be the essential breccia of the formation are given below in the petropgraphy.
(Petrography-1)

Samples	Sample No. 76123001 Collected at the lower stream of the Zunil Water Fall.
Photograph	PHOTO M-14
Petrology	Biotite hornblende Andesite
Phenocryst	The maximum size of plagioclase is 1.4mm with fractured facies and internally worm eaten. The largest hornblende is 1.2mm and generally 0.2-0.6mm in size with Z'=dark green, X'=green with optical properties. Biotite is 0.2-0.6mm in size with Z'=dark brown,

	X'=yellowish brown. No opacitic effects are observed with hornblende and biotite, but partly altered.
Groundmass	The clay minerals are formed, but the details are unknown.

(Petrography-2)

Samples	Sample No. 76123002 The lower stream of Zunil Water Fall
Photograph	PHOTO M-15
Petrology	Biotite hornblende andesitic pumice
Phenocryst	The plagioclase crystals of max. 2.0mm with saussulite rim in most of them. The largest hornblende is 0.9mm with Z'=green, X'=light yellowish green. The biotite with max. size of 0.7mm with Z'=brown, X'=light yellow.
Groundmass	Glassy and vesicular.

(9) Terrace Deposit

The river terrace is highly developed along the Samala River and the terrace deposit surface is just about at 2,100m elevation. (PHOTO F-45) On the top of the Zunil Water Fall Lava, no terrace deposits are found.

Although it is not clear, as the flat plane at NE end of Line-1 and the west end area of Line-3 are covered by alluvial cone, whether it could be considered as a remnent structure of the terrace deposit or it may be possible that the terrace deposit may be found below the Zunil Water Fall Lava.

Near the Zunil village there is very little difference in elevation between the present river bed and the terrace surface, but it could be considered that the Zunil Water Fall Lava has dammed up the Samala River, that the river bed has been elevated.

According to the report the Pan World glacial epoch causing the sea water level fluctuation was considered up to the terrace deposition as Pleistocene but no evidences were found to determine the geological age.

Moverover, the high elevation terrace deposits were not confirmed but the flat plains at 2,300m elevation may correspond to it. The flat plain itself is Zunil Formation at the same time.

(10) *Scoria and Pumice Sediments*

All the formations, except the Zunil Water Fall Lava, Cerro Quemado Lava and alluvium formations are covering the old topographic surface. Even with the stratigraphy or the geologic column confirmed the formation is consistent from the 2,700m elevation SE of Tzanjoyam village to 1,900m elevation at the lower stream of the Samala River.

The scoria and pumice rich formations are alternately deposited with highly porous (foamy) sediments and without hardly any accidental breccia included. From the nature of distribution and the characteristics of the sediments, it has been concluded as airborne sediments.

Moreover, this airborne sediments are exposed at many locations (PHOTO F-27, 28, 32, 80), but the distribution of strata (formation), geological distribution and the geological structure are not recorded in Fig. 3-3, 4.
The origin of its eruption is not clear.

(11) Zunil Water Fall Lava

To the west of Zunil village the distribution is indicated in a fan shape deposition. So far, it was considered to be eruped from the SE corner of the Quemado Volcano foot hills, but the lava was traced to reach the 2,815m Peak (PHOTO F-64), which vicinity seems to be the point of eruption, (the Lava is distinctly differentiated from Almolonga Lava by existence of biotite).

As Williams (1960) has pointed out, it is considered that the lava has dammed up the Samala River to form a lake basin like plane, where the present Zunil village exists.

From the fact that the airborne scoria sediments and terrace deposits are not found, and the humic soil is poorly developed and the vegitation is limited to sparcely grown short shrubbery (PHOTO F-85), the geological age is considered to be very new lava flow. Moreover, the outcrops covering the Zunil Formation was confirmed (PHOTO F-35, 75, 78).

The Lava consists mainly of blocky lava flow with highly developed facies from vesicular to auto brecciation at the basement and also at the upper part of the lava flow (PHOTO F-56).

(Petrography)

Samples	Sample No. 76122806 Sampled at the peak of 2,815m Sample No. 76123004 Sampled at the Samala River
Photography	PHOTO M-16, 17
Petrology	Hypersthene augite bearing biotite hornblende andesite
Phenocryst	The plagioclase crystals max. 3.5mm with

	idiomorphic crystals generally of 0.5mm in size. Often times the crystals have saussulite rim and internally worm-eaten. The hornblende crystals max. 1.2mm generally 0.2-0.5mm size idiomorphic crystals, Z'= reddish brown, X'=brownish yellow with optical characteristics. The biotite crystals are 0.1-0.6mm idiomorphic crystals, Z'=dark brown, X'=yellowish brown to yellowish green. The pyroxene crystal is about 0.1-0.2mm and other minerals with small amount of quartz and opaque minerals.
Groundmass	Consists of glassy flow texture with very fine plagioclase hornblende, biotite, crystallite and at times with opaque minerals.

(12) Cerro Quemado Lava

It is distributed in the NW section of the survey area. The vegitation growth in the area covered by the Lava has a distnction of KUROMATSU PINE (PINUS THEMBERG) growth.

Whereas, in contrast to the subject area, the broad leaf trees cover the Almolonga Lava area. (PHOTO F-46)

The humic soil is poorly developed that the geological age is considered to be considerably younger.

The stratigraphy relation between this Lava and the Zunil Water Fall Lava is unknown, but at least it is the upper formation than the airborne scoria sediments.

(Petrography)

Samples	Sample No. 76122102 Sampled from the west of 2,815m peak
Photography	PHOTO M-18
Petrology	Pyroxene bearing biotite hornblende andesite
Phenocryst	Plagioclase crystals max. 2.5mm with idiomorphic crystals partly corroded. Hornblende crystals max. 1.7mm mostly opacitic, Z'=brown, X'=yellowish brown. Biotite crystals about 1.0mm in size with idiomorphic crystals, Z'=reddish brown, X'=yellowish brown. Pyroxene and some opaque minerals recognized.
Groundmass	Consists of glassy and very fine crystals of plagioclase, biotite and hornblende with intersertal texture.

(13) 1,785 Lava

According to Williams (1960), it is believed that the lava was extruded from Quemado Volcano in 1,785. It is a hornblende biotite andesite, but no microscopic study has been conducted. Even at present the "KUROMATSU PINE" is sparcely grown, and it is clearly distinguishable from other lava. (PHOTO F-47)

(14) Alluvial Cone and Alluvial Deposit

The alluvial cone is distributed in the SW of the Zunil village containing breccia as large as a human head, but no granitic breccia is found.

The alluvial deposit is distributed in the Samala River beds, besides containing above mentioned breccia of granodioritic breccia as large as a human head.

By this survey the granodioritic outcrops were discovered by tracing the river bed breccia, but the great amount of large breccia (the Samala River bed breccia is larger than the ones from the Pachamiya River bed), which is an indication of a strong possibility of existence of a large granitic outcrop very near.

The Samala River is a rapid cataract with severe erosion that there exists a several meter high cliffs between the present alluvial deposit and the present river bed itself. (PHOTO F-58)

3-3-2 Faults

In the assigned survey area no key bed was found that it is difficult to analyze the geological structure.

Excluding the Zunil Formation, all the formations are of continental sediment origin covering the old river and canyon topography, that the analysis of geological structure is more difficult.

By the present survey from number of results of the geological phenomena, electrical survey and seismic survey, the faults are confirmed or estimated as follows:

(1) Fault A

The fault is estimated to be along the line connecting the two granodiorite outcrops at the Chuyul and the Pachamiya Rivers.

In the aerial photograph the lineament recognized in the east of Barneario Aguas Amargas corresponds to the NE extention of the fault.

As the granodiorite outcrops are not found where the elevation is low like the Samala River bed, the possibility of the fault submergence on the west side is feasible. In this case the displacement would be considered at least to be about 300 meters.

(2) Fault B

It is estimated to be along the east side of the rhyolite outcrops along the Samala River. The reasons 1) where the Pachamiya River and the canyon of Line-4 meets the Samala River, the river bends sharply to south east, 2) rhyolite is exposed as a fenster at the east bank of the Samala River, the existence of anticline structure below Zunil Formation is possible and the east side border of it may possibly be a fault.

As a result, the east side of the fault may be considered to be relatively submerged.

This fault clearly coincides with the lineament passing throuth Fumarole Negra interpreted in the aerial photograph, and its NE extension coincides with the fault between No. 41 - 51 on Line-2, estimated by the electrical survey.

(3) Fault C

With the same reasons as described previously for Fault B, the fault is estimated to be along the western rim of rhyolite fenster. Nearby Zunil Water Fall it is confirmed as the fault cutting the Zunil Water Fall Lava, but the strike and dip are not clear. The west side of the fault is relatively submerged. (PHOTO F-34)

This fault is further confirmed by the electrical survey as well as seismic survey. That is, near No. 81 on the electrical survey Line-2 and near No. 10 on the seismic survey Line-B the fault estimated independently coincides with the fault location.

(4) Fault D

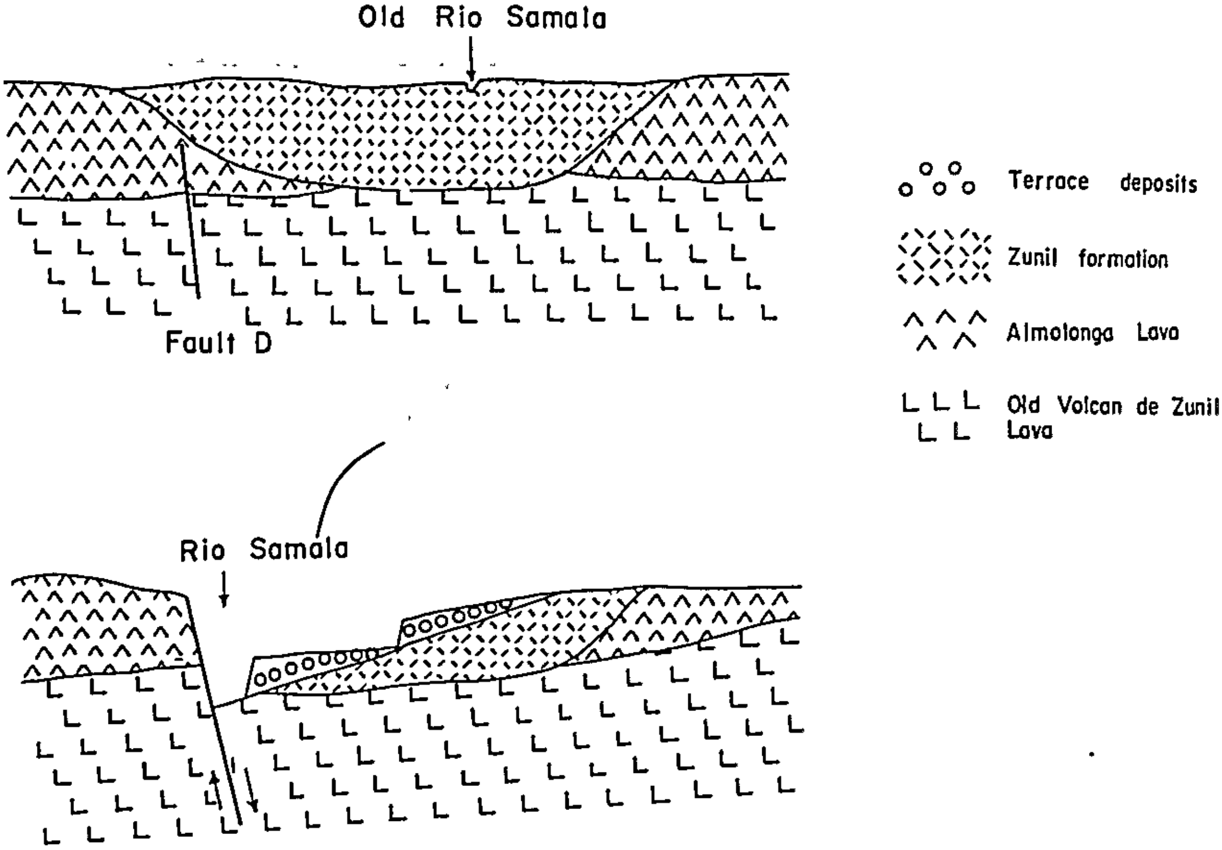
In the western area of the electrical survey Line-1, the fault is estimated from the hot springs and solfataras lined up in a straight line in NE to SW direction.

The high geotemperature at No. 40 on the seismic survey Line-A indicates the possibility of the fault being located on the extension of NE direction and the fault estimated to be located near No. 30 on the seismic survey Line-A may also be a part of Fault D.

The movements of Fault D is not clearly understood, but by estimating from the various phenomenon, there is a possibility that the west side of the Fault D has been elevated.

1) A flat plain is located at about 2,350m elevation, which is 500m NE of NE end of Line-1. (PHOTO F-86)
   The geology of the flat plain was not confirmed, but it is believed to be a terrace plain or equivalent to the upper surface of Zunil Formation.
   In the former case, the west side of the fault is expected to have been elevated about 200m. In the latter case there seems to be no displacement by faulting.

2) On the west bank of the Samala River within the actual survey area conducted, the distribution of Zunil Formation and the terrace plain were not confirmed.
   The fault running along the Samala River as a boundary, the west side was relatively elevated and it could be considered that the river bed of the Samala River was moved westward.
   This tilting is shown below in a schematic profile.



3) In general the basement of volcanoes is considered to have been elevated.

(5) Fault E

Fault E was confirmed at the cliff (PHOTO F-33) along the road on the east side of Zunil village. Zunil Formation is cut off by the fault and the NE side is submerged about 10m.

The NE extension of the fault coincides with the Chuelo Chinima River, which cuts across the Almolonga caldera structure. Furthermore, other parallel fault of NW-SE strike were confirmed nearby the water intake of the hydroelectric power plant and the north side of the fault is submerged approximately 15m. (PHOTO F-16)

(6) Fault F

It was confirmed along the road, about 300 meters north of the west end of Line-4. (PHOTO F-80, 81) It cuts across the air-borne scoria bed, and the west side is relatively elevated.

(7) Fault G

The sharp cliff, extending SW from nearby the east end of Line-3, may possibly be a fault cliff.

As Zunil Formation abuts the fault, its formation age is older than the previously mentioned fault.

The fault is considered to be the same fault as estimated at No. 20 on the seismic survey Line-C and at No. 81 on the electrical survey Line-3.

(8) Fault H

In north of Balneario Aguas Amargas the distribution of Zunil Formation and the Old Volcan de Zunil Lava practically contacts at vertical plane structure.

Zunil Formation is not found in the lower stream of the Samala River and considering the possibility of Zunil Formation being the same bed as Cantel Formation, depositing at the Quezaltenango basin structure, the fault may possibly be located at the southern fringe of the Quezaltenango basin structure.

A part of these faults cut across Quarternary beds and the solfataras distribution is controlled by the fault structure. Therefore, at least a part of these faults have been moving during the Quaternary, that is, an active fault.

3-3-3 Geological Structure and the Depth of Granite Body

Considering from the conditions of the distribution of the aforementioned faults, the area between Fault A and Fault D, with width of approximately 3km, indicates at least a collapse structure running in NE to SW direction. The southern limits may possibly be Fault G or Fault H. The age of formation of the collapse structure is most probably about the same time as the formation of Quezaltenango basin structure.

In general the collapse structure is very favorable for a water reservoir structure. Even in this area this graben structure is considered to function as a water reservoir. As mentioned previously, from the results of this survey, the key bed is missing in this area, and it is very difficult to estimate the depths by the geological survey from the Samala River bed to the upper surface of the granodiorite. Assuming the upper surface of the granodiorite to be located 200m below the Samala River bed, from the difference in elevation the submergence of Fault A will be 500m.

At the Pachamiya River it was confirmed that the rhyolite lava covers the granodiorite at unconformity, but in the western area of Fault A, there is a possibility of an existence of a separate lava group, which is not exposed as outcrops between the rhyolite lava and granodiorite.

In this case, if the physical properties of the granite and the lava are similar, it will become very difficult to distinguish the differences by geophysical survey.

At any rate, the granite group are estimated to have been step-faulted gradually to the western volcanic region where Cerro Quemado and Santa Maria etc. have been still active up to the present.

3-4 Geothermal Indications

By the present survey some geothermal indications were newly discovered in the western foothills on Line-1.

By considering the information of the first survey the geothermal alteration, the hydrogeology of hot springs and the geochemistry of the hot spring water will be discribed.

3-4-1 Geothermal Alteration

(1) The distribution of the geothermal alteration belt zone.

As indicated in Fig. 3-2, the geothermal alteration belts are recognized in the following five regions:

1) The western foothills of Line-1.

2) 500 meters south of west end of Line-2.
(along the National Highway and the Samala River)

3) Area between Zunil Water Fall and Fumarole Negra.
(along the Samala River)

4) Balneario Aguas Amargas and its east side region.

5) The old sulphur mine site south of Tzanjoyam.

Among the above regions the geothermal alteration outcrops are found clearly in a straight line from NE to SW direction on the western foothills of Line-1. The geothermal alteration of Zunil Water Fall~Fumarole Negra area extends from NE to SW direction in an elliptical distribution.

No solfataras are recognized in the alteration area 500m south of the western end of Line-2, but the other alteration zones are accompanied by solfataras.

There are many unknown factors concerning the geological age of geothermal alteration, but due to inclusion of altered rocks in Zunil Formation the geothermal activities have been intensive prior to Zunil Formation.

At the outcrops of Fumarole Negra the Old Volcan de Zunil Lava is extremely altered, but Zunil Formation covering the upper formation shows weak indications of alteration. (PHOTO F-37)

(2) The microscopic study of the altered rocks

Among the altered rocks, the weakly altered portion was microscopically observed. The sampling location is shown in Fig. 3-4.

(Petrography)

Sample	Sample No. 76121904 Collected south of Balneario Aguas Amargas Sample No. 76121906 Collected south of Balneario Aguas Amargas Sample No. 76122002 Collected at Fumarole Negra Sample No. 76122006 Collected at Fumarole Grande
Photograph	PHOTO M-4, 19, 20, 21
Petrology	Altered rhyolite
Phenocryst	Plagioclase of 0.7-1.2mm size of idiomorphic crystals, partly or completely altered. Biotite size max. 0.7mm and generally 0.1-0.7mm with alteration. From the xenomorphic crystals the phenocrysts look like

	pyroxene hornblende, but the alteration is so excessive that it is difficult to identify. Other minor minerals are opaque minerals. The altered minerals are so fine that it is difficult to identify even under the microscope.
Groundmass	Consists of glassy to fine plagioclase micro-crystals with evidences of flow structure and perlitic texture.

(3) X-Ray diffraction analysis of altered rocks

The typical samples of strongly altered and weakly altered rock samples were collected from the center and surroundings of each altered zone for the X-Ray diffraction analysis. The locations of the samples are shown in Fig. 3-4 and the results of the X-Ray diffraction are also shown in Table 3-1, 2.

The results of the analysis revealed that the typical ground surface rocks were acidic leached altered rocks.

The details are as described below.

1) Montmorillonite: Formed along the outer rim of altered zone, (PHOTO F-75) and also found in the fault clay (PHOTO F-17).
   In the granodiorite weak indications were also observed but further consideration is required to determine whether it was caused by the geothermal alteration or by weathering.

2) Sericite: Discovered in the samples collected at one km east of Balneario Aguas Amargas. The original rock is rhyolite.

3) Kaolin: Excluding the samples collected at Fumarole Negra and at a point south of Tzanjoyam, the minerals were found

Table 3-1 List of Altered Minerals

Sample No.	Rock character in handspecimen	Altered Minerals														Primary M.			Remarks
		montmorillonite	sericite	kaolinite	alunogen	stilbite	K-feldspar	α-cristbalite	tridymite	quartz	β-cristbalite	calcite	alunite	pyrite	aragonite	plagioclase	biotite	hornblend	
76121803	fibrous material, white				29														
76121807-1	weakly altered andesite, grey					1		4		2			5			4			
76121807-2	strongly altered andesite, white									1									
76121904	strongly altered rhyolite, cream yellow		3	3				3		4			5						ref. TS
76121906	strongly altered rhyolite, white			9				4		2			4			1			
76122002-1	strongly altered rhyolite, white			2				4	4	1									
76122002-2	weakly altered rhyolite			9			9	3		1		1					5		ref. TS
76122005	strongly altered tuff, white, powderly							2											
76122006	weakly altered rhyolite, dark grey							1			2		5						ref. TS
76122008-1	strongly altered rhyolite, white~grey							1			2		8						
76122008-2	weakly altered rhyolite, grey							2					3	3					
76122010	dark brown material							3		4									
76122302	weakly altered tuff, white							3		2									
76122901	strongly altered andesite, white												3						
76122904	altered andesite with travertine			2								7							
76122905	weakly altered andesite, grey							3	7							2			
76122906-1	strongly altered andesite, white							1	7	1			7						
76122908-2	weakly altered andesite, white							3	7							3			
76123001	weakly altered tuff	3								1						15	7	6	ref. TS
76123002	weakly altered tuff	3								1						14	3	3	ref. TS
77010501	unaltered granodiorite	1					11			4						10	5		ref. TS
77010603	weakly altered andesite, grey	3						1		4						12		1	
77010604	strongly altered andesite, white							2			2		6						
77010605	strongly altered andesite, white	3		3				1	3				7			4			
77010606	weakly altered andesite, grey	3						3						1		8	1		
76121702	fault material	4						1		1						11			

* Number in this table show reflection peak number of X-Ray analysis
* TS: Rock Thin section data

in majority of leached samples collected from the center of the white altered zone.

4) Alunogene: Found in the altered zone south of Tzanjoyam. The mineral substance is crystallized in feather form between the rock fractures.

5) Stilbite: Found in the samples collected at the sulphur mine site south of Tzanjoyam, but the X-Ray diffraction peak was only found at one place.

6) Potassium Feldspar: Found in the weakly altered rhyolite and granite, and it is considered to be a primary mineral.

7) α-Cristobolite: Found in samples, excluding tuff and granodiorite, with some variations. The major part of minerals are considered to be a primary minerals.

8) β-Cristobolite: Found partly in perlitic rhyolite and andesitic rocks. The lava group are considered that it has never been buried in depth and also from the microscopic study, the minerals are not product of geothermal alternations, but products of auto alteration minerals formed at the time of the lava eruption.

9) Tridymite: A typical altered mineral found with kaolinite in the leached alteration formation in this area.

10) Calcite: Found in the samples collected from the altered zone west of Line-1. As the concretions of the hot springs are recognized in the rock fractures, the indication of X-Ray diffraction may be only a carbonate deposition.

11) Alunite: Found from most of the samples collected from the leached alteration rocks..

The fact that the alterated rocks in this area are characterized by kaolinite, tridymite and alunite minerals, coincides with sulphuric acid hot spring water found nearby the altered zone. Furthermore, the fact that no high temperature altered minerals (for instance, like wairakite, pyrophyllite) are found indicates that the altered lavas are the continental sediments in nature and never been buried in depth, which is a proof that the gas emission took place under the atmospheric pressure.

No alteration minerals by neutral hot spring water were considered feasible, but this is due to the neutral hot spring of low temperature and a head of NaCl hot spring being below present surface. However, montmorillonite found in the Samples No. 7612-3001 and No. 76123002 may have been formed by the gushing hot spring nearby.

3-4-2 Hot Spring Concretions

The hot spring concretion are formed near the gushing hot springs of weak alkali to neutral in western area of Line-1 and along the Samala River (PHOTO F-14, 19, 55, 56, 65). It is also formed on the cliff nearby the western end of Line-4 (PHOTO F-74), but at present no gushing hot springs are recognized.

In the cross-section of white to grayish white concretion annular rings of fine bedding structure are seen. The part of deposition under the hot spring water is soft, but the other part above the hot spring water is very hard.

In Table 3-2, 3, 4 the results of the X-Ray diffraction analysis and the chemical analysis are shown.

The hot spring concretions are possible to be classified into two types, namely, one type as $CaCO_3$ rich carbonate deposit consisting of calcite and aragonite, and the another type as SiO_2 rich

Table 3-2 List of Travertine Minerals

Sample No.	Rock character in handspecimen	Altered Minerals			
		Tridymite	Quartz	Calcite	Aragonite
76122206	Travertine, white			5	9
76122902-1	Travertine, central part			5	9
76122902-2	Travertine, marginal part			5	
76122007	Travertine	4	4	4	

Table 3-3 Chemical Composition of Travertine

Sample	76122007	76122206	76122902-1
SiO_2 %	81.64	18.52	1.30
Al_2O_3 %	0.130	0.140	0.076
MgO %	0.81	4.71	2.49
K_2O ppm	337	963	385
Na_2O ppm	701	3936	3003
MnO ppm	116	4351	20252
Fe_2O_3 ppm	3511	1278	755
CaO %	11.59	46.22	65.29
TiO_2 ppm	60	60	60

Table 3-4 Chemical Composition of Hot Water in Zunil Area

No.	Sample No	Locality	(°C) Temp	(1/min) Volume	FPH	LPH	(mg/1) Cl	(mg/1) HCO_3	(mg/1) SO4	(mg/1) Na	(mg/1) K	(mg/1) Ca	(mg/1) Mg	Na/K	Remarks
1	Z-4	Zunil Water Fall	60	5	7.3	8.14	84.07	242.52	69.15	146.0	13.8	15.23	7.48	18.1	with travertine
2	Z-6	Zunil Water Fall	63	5	7.4	7.78	94.35	387.66	86.44	186.0	14.2	16.03	7.23	22.5	with travertine
3	Z-16	Western end of Line 4	61	10	7.5	7.56	161.69	667.54	169.17	272.5	37.2	44.48	60.32	12.5	with travertine
4	Z-19	Balneario Aguas Amargas	72	6	2.3	2.25	30.24	0.00	1180.47	92.5	30.4	34.05	16.85	5.2	
5	Z-20	Fumarole Grande	78	17	8.0	9.08	717.73	126.16	182.75	585.0	53.0	3.20	0.96	18.7	with sinter
6	Z-21	Los Baños	64	15	7.4	7.38	55.84	7.20	75.73	95.0	8.0	14.02	10.61	20.7	with travertine
7	Z-23	Los Baños	51	5	7.0	6.85	42.94	15.92	31.69	80.5	10.4	6.01	24.85	13.5	with travertine
8	Z-24	Zunil village	47	7	7.3	7.30	62.49	207.00	53.51	115.5	15.4	12.82	10.61	12.9	with travertine
9	Z-26	Zunil village	40	8	7.2	7.03	36.29	224.14	41.16	88.5	14.0	13.62	15.44	10.7	with travertine
10	Z-27	Zunil village	50	3	7.3	7.25	101.81	214.34	71.62	135.5	14.0	14.42	7.96	16.4	with travertine
11	Z-29	Hydroelectric power station	51	10	7.1	7.18	47.37	165.34	16.05	70.5	12.0	10.02	6.99	9.9	with travertine
12	Z-30	Xejuyub	45	5	6.9	6.91	50.04	126.16	4.12	34.0	4.0	11.22	7.96	14.8	with travertine
13	Z-31	Balneario Fuentes Georginas	35	8	1.5	2.32	20.16	0.00	968.91	104.0	37.0	46.05	33.75	4.8	swimming pool
14	Z-32	Xejuyub	50	7	6.9	6.99	9.07	122.48	5.35	22.5	5.0	10.42	7.48	7.5	with travertine
15	Z-33	Hydroelectric power station	57	4	7.3	7.12	56.45	156.78	19.76	79.5	32.8	9.61	5.54	4.1	with travertine
16	Z-34	Balneario Fuentes Georginas	27	2	2.5	2.12	24.19	0.00	1534.04	151.0	36.4	66.10	31.35	7.1	with travertine
17	Z-35	Fumarole Negra	54	5	5.5	5.20	4.03	26.94	140.36	26.0	9.8	22.04	10.61	4.5	
18	Z-36	Fumarole Negra	96	4	3.5	3.45	20.16	0.00	266.31	34.0	31.6	32.05	22.90	1.8	
19	Z-37	Western area of Line A	25	10	6.7	6.98	87.29	618.56	95.90	104.5	24.6	36.07	53.32	7.2	like mud pot
20	Z-38	Western area of Line A	96	3	4.6	4.13	16.53	28.16	311.17	34.0	25.8	5.61	42.22	2.2	with travertine
21	Z-41	Banos Termales los Vahos	25	0.5	6.5	6.50	3.02	17.14	0.00	10.0	1.2	2.40	0.24	14.3	

silicate deposit consisting of calcite, quartz and tridymite.

The former is deposited near HCO_3 type gushing hot spring and the latter is deposited near the NaCl type hot spring, and each characteristics coincide with the chemical composition of the hot spring water, respectively.

3-4-3 Chemistry of Hot Spring Water

Regarding the hot spring water in this area, many chemical analysis were conducted to determine the composition at the time of the first survey (1973).

In this survey, the analysis was limited to the main composition. The results are shown in Fig. 3-5. Some of the pH values measured at site and in the laboratory indicated very large discrepancy, but it may be due to the time elapse of several months to analyze the samples. Moreover, the amount of hot water gushing was estimated visually.

In the Fig. 3-5(a) ΣCO_2 is used as HCO_3 is used to measure alkalinity that the correction is necessary to correct pH influence. The following equation was used to make the conventional correction.

$$\Sigma CO_2 = [HCO_3] \cdot \frac{[H^+]^2 + [H^+] \cdot K_1 + K_1 \cdot K_2}{[H^+] \cdot K_1}$$

where,

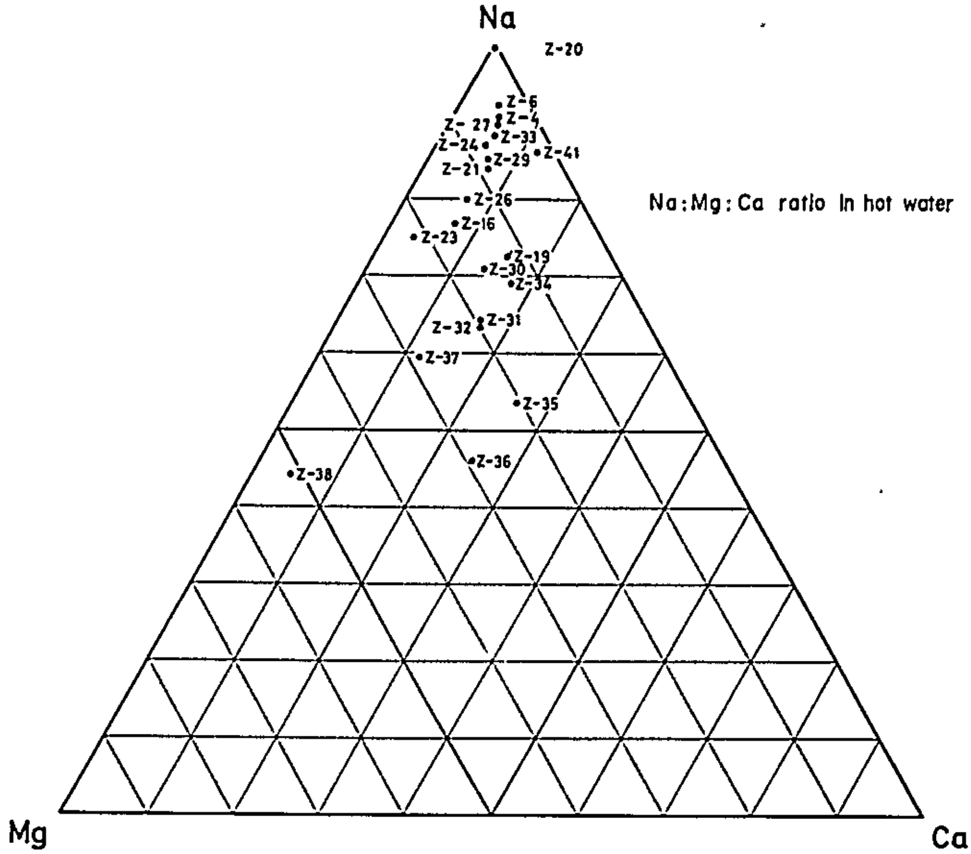
$K_1 = 3 \times 10^{-7}$

$K_2 = 6 \times 10^{-11}$

The hot spring water in this area is classified into three categories according to Fig. 3-5 as follows:

Weak alkaline NaCl type

Neutral HCO_3^- type



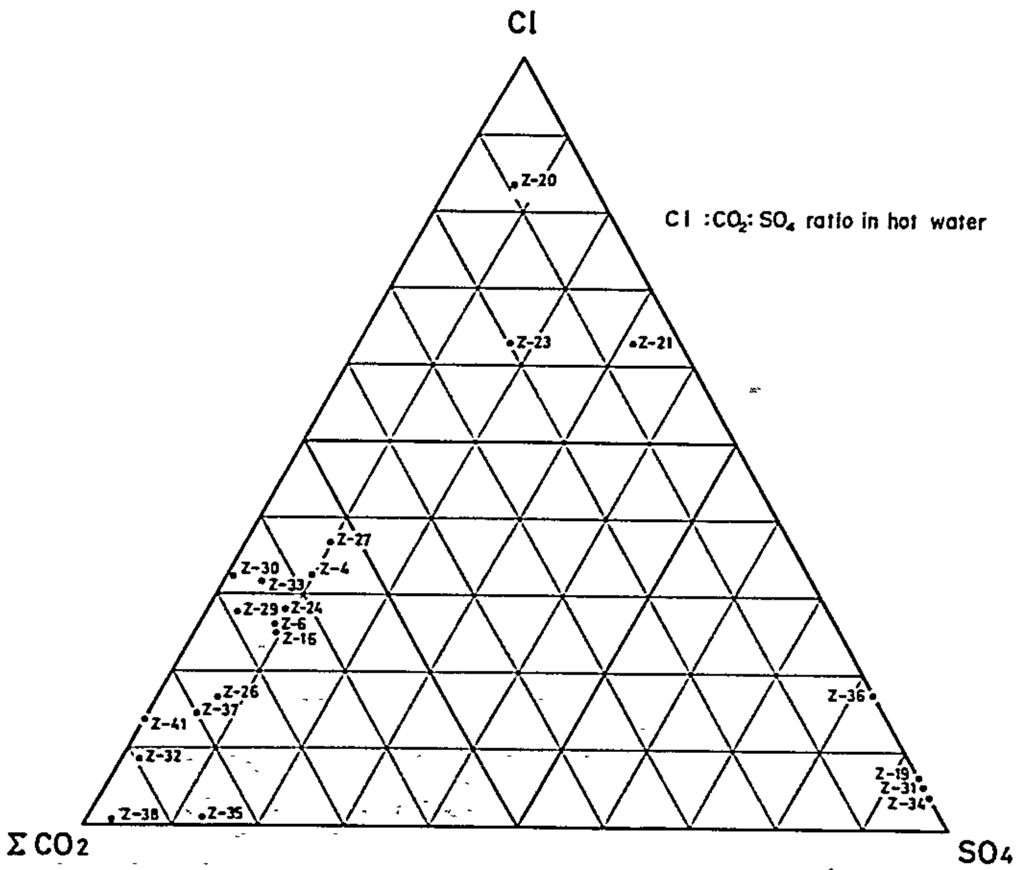


Fig.3-5 Atomic Ratio in Hot Water

Acidic SO_4 type

(1) Weak alkaline NaCl type

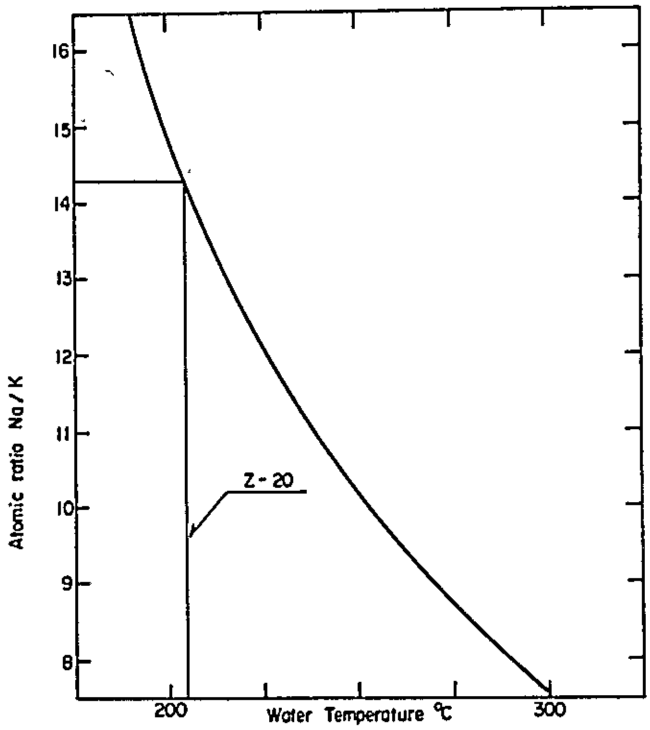
The hot springs at Fumarole Grande and the hot springs discovered this time at western end of Line B belong to this type. The hot springs at Los Baños gave very close results as this type, but from the first survey it is classified as HCO_3 type.

The hot spring of Z-20 (Fumarole Grande PHOTO-36) is not only rich in NaCl, but also over saturated with SiO_2, which coincides nicely with the SiO_2 deposition nearby. This time the analysis for I, Mn, Zn and Al was conducted for the first time. No differences are found in the contents of Mn, Zn and Al in the ordinary hot spring water, but it is noteworthy that the content of iodine is very high.

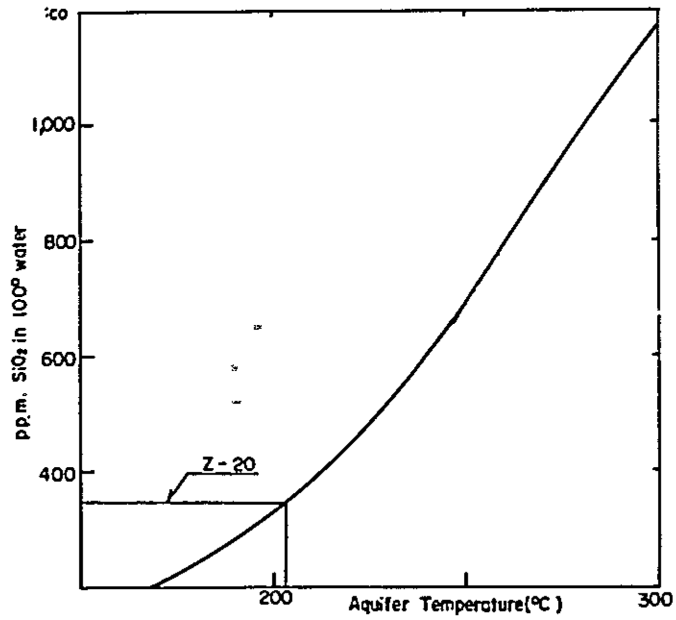
According to the experiments of Ellis et al (1964, 1967); in general the hot water at depth is saturated with SiO_2 and it is considered that the hot water coming in contact with the rocks with higher temperature would generally contain higher sodium to potassium ratio (Na/K) as well as rich NaCl. Even if assuming that the influence of surface water mixing in this type of hot spring water is disregarded, as indicated in Fig. 3-6 the hot water at depth may be estimated to be 200-250°C from the values of Na/K and SiO_2.

(2) Neutral HCO_3 type

Including the new hot springs discovered this time in the area, the majority belongs to this type. The characteristics is rich in HCO_3 and low in SO_4, and the calcium to magnesium ratio (Ca/Mg) is close to 1:1 and near each gushing hole calcium carbornate concretions are found.



The variation with temperature of the ratio Na/K in water in equilibrium with albite and K-feldspar.



The relationship between silica concentrations in 100℃ waters at the surface and the original underground temperature of water saturated with quartz. Cooling of water is by adiabatic isenthalpic expansion into steam and water on route to the surface. after Ellis (1970)

Fig. 3-6

Geochemical Temperature in Deep Level

By this fact it is considered that the shallow underground water or the surface water is heated up by steam or ground temperature to form the hot springs.

(3) Acidic SO_4 type

The samples of hot spring water collected from nearby solfatara belong to this type, and it is a hot spring produced by heating the surface water or the shallow underground water by the steam containing H_2S gas.

Without exception wherever the hot spring is flowing, the white altered rocks (consist of kaolin and alunite, etc.) are distributed, indicating the leaching action progressing with the acidic hot spring water.

3-4-4 Hydrogeology of Hot Spring Water

The acidic SO_4 type hot springs in this area seem to be the heated creek water.

In other words, at Balneario Aguas Amargas, the creek water flowing through the rapids happens to encounter the solfatara to produce the hot springs (PHOTO F-5, 6) and the process is the same for Balneario Fuentes Georginas (PHOTO F-6, 29).

The acidic hot spring of Fumarole Negra was recently (after the second survey) formed by the solfatara gushing through the gravels to heat the branch stream of the Pachamiya River and the underflow water.

Regarding the NaCl type hot spring at Fumarole Grande (PHOTO F-36, Z-20) it has been confirmed that it is gushing from the cracks of rhyolite rocks.

Topographically, as Fumarole Grande is located at 1,900m elevation and about 200m to the east of it the Pachamiya River is flowing near Fumarole Negra at 2,020m elevation, that there is a possibility of river water flowing through cracks of rhyolite rocks to be mixed together. There is also a possible indication that the geyser is being produced by mixing of hot water higher than the boiling point and cold water.

The gushing conditions of the HCO_3 type hot springs are varied depending on location. At Los Baños hot spring (PHOTO F-11) the spring itself is protected by concrete that the details are unknown. but at least one of them (PHOTO F-12) is gushing from the cracks in Cantel Formation (It is considered to be the upper bed of Zunil formation).

To the east of the hydroelectric power plant (PHOTO F-18, 19) and the west of Zunil village (PHOTO F-14) it has been confirmed that the hot springs are gushing from the horizontal fractures (bedding) and vertical cracks (joints).

At the lower stream of Zunil Water Fall (PHOTO F-56, 75) the hot springs were confirmed to be gushing through the boundary between Zunil Water Fall Lava and Zunil Formation. Regarding the hot springs west of Line-1, the details are unknown as they are gushing through blocky rocks.

The hot springs located from Fumarole Grande to the lower stream of the Samala River are all gushing through the present river sediments (gravel beds). (PHOTO F-55)

The hot springs gushing near the fall in northern part of the west end of Line-4 are spring out of the cracks of agglomerate facies of Almolonga Lava. No other hot springs are recognized at present, but the hot spring concretions (PHOTO F-74) are exposed along the road on the southern part of the west end of Line-4, which is an indication that at one time the hot spring water was flowing through the breccia of agglomerate bed of the Cerro El Galapago Lava.

Kimura et al (1965) used tritium as a tracer and pointed out that the flow of the underground water under natural conditions does not follow the Darcy Flow as it has been considered in the past, but that it has been verified as being the Bingham Flow. (Fig. 3-7)

Accordingly, the natural flow of water is not simply controlled by the porosity of the beds, but basically controlled by the fractures, and even in the unconsolidated gravel beds, it flows along the specific water channels. Even in the highly porous tuffaceous rocks, the hot spring water is flowing along the fissures of the bed or along the boundary with other formation and it is not found to be flowing through tuffaceous formation uniformly.

In this area it is considered that tuffaceous Zunil Formation is less permeable than the lava group with many joints, voids (foaming pore) and gravel pore (breccia voids of volcanic agglomerate facies).

In general the underground water has a constant tendency to maintain a horizontal level. The upper limits of the gushing points of HCO_3 type hot springs are concentrated at about 2,100m elevation, and it may be considered that they belong to the same water bearing formation.

The hot spring that gushes along the Samala River at the lower part of Zunil Water Fall seems to come from 2,100m elevation flowing along the surface or near the surface and then as an underflow of Zunil Water Fall Lava, alluvial cone and present river gravel bed down to lower elevation along the Samala River beds to re-gush again.

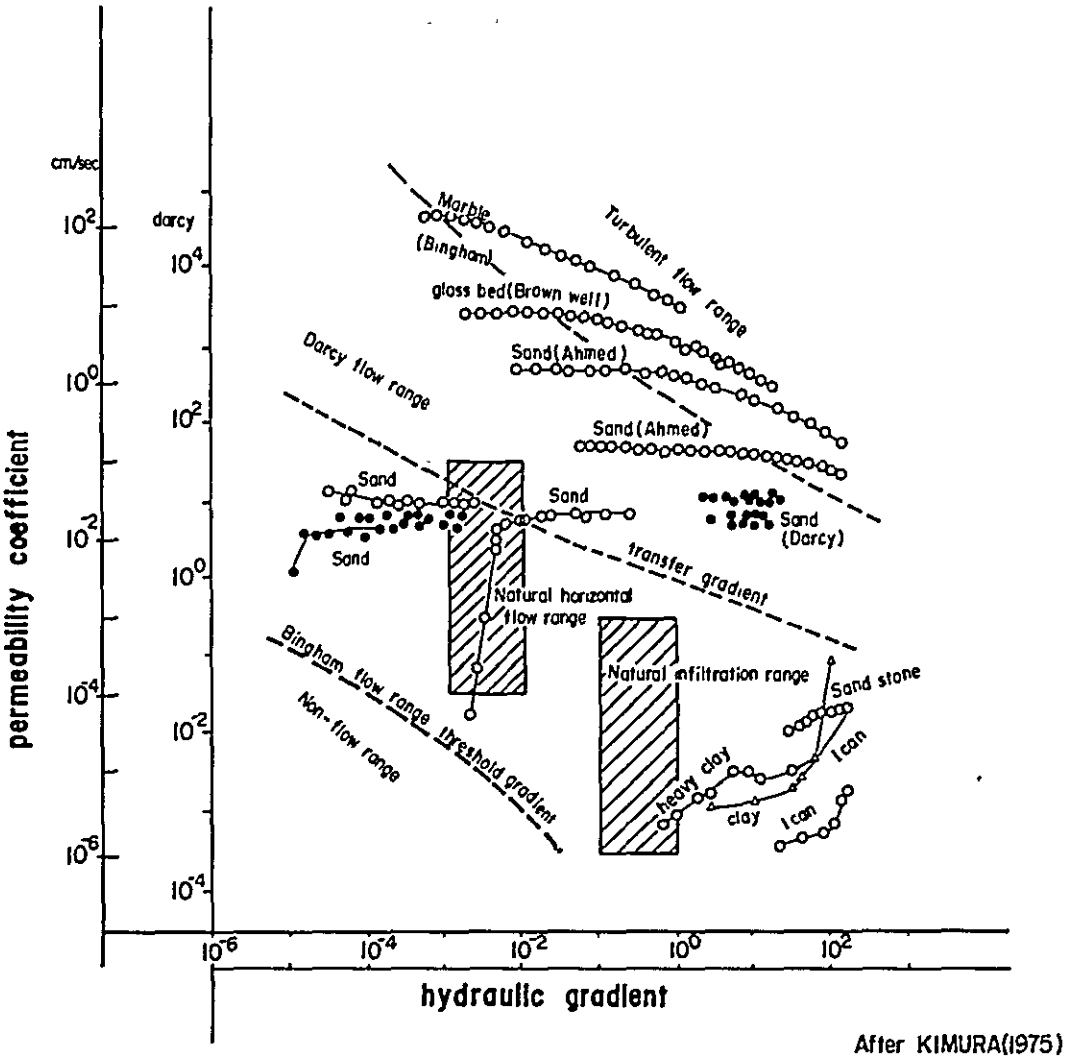


Fig. 3-7

Flow of Natural Underground Water

The HCO_3 type hot springs are concentrated on the west bank of the Samala River. Furthermore, the gushing holes of Fumarole Grande coincide with the gushing holes near the west end of Line-4, which are located at a higher elevation.

The hot spring concretion found on the outcrops located south of the western end of Line-4, indicates that the hot spring water flowing at one time was changed by hydraulic gradient caused by the errosion of the lower part of the Samala River. Therefore, the hot spring water surface submerged and the gushing hot springs disappeared at present.

From the results (Fig. 5-15) of the geothermal temperature measurements the tendency is observed that the isothermal contours from the western end of Line-B is sloping toward the river bed of the Samala. Then, the fact that the temperature of the hot spring water at the Samala River bed being 50 ~ 70°C indicates that the hot spring water gushing nearby the western end of Line-B is flowing underground towards the Samala River.

From this survey the hot spring of Los Baños was confirmed to be the intermediate characteristics between NaCl and HCO_3 types. Moreover, from the fact that the elevation is relatively high as 2,200m, the origin of the Zunil area HCO_3 type hot spring water may possibly be originated from Almolonga basin structure.

However, as the analysis of the first survey and this survey differs, further re-checking is necessary in the future.

Henceforth, the object of the geothermal development will be NaCl type geothermal fluid. But, in spite of the head of the NaCl type hot spring water being as high as 2,060m elevation, this type of hot springs are not found in the southern part of Fumarole Grande, which may indicate an aquifer basin structure dipping to noth and the geological structure controlling it as a whole.

As described in the section 3-3-2, the fault running near No. 81 of Line-4 and the geological unconformity north of Balneario Aguas Amargas may possibly be restricting the southern limit of the aquifer structure.

3-5 Discussion

Most of the geothermal resources in the world exist in the graven zone with the favorable conditions for the water reservoir which could transfer geothermal heat.

In general the aquifer basin structure is controlled by the distribution of the permeable layers and the non-permeable layers, but as the high temperature water has very low viscosity coefficient, it is believed that the perfect non-permeable beds do not exist, unless the beds are solid without fractures. Therefore, the structure to control the geothermal reservoir is not the characteristics of the individual geological formation itself, but it is rather considered to be a combination of large geological structures.

In general the effects of drainage of the geothermal stream from the production well is considered to affect over several km. The subsurface water stream flow is not controlled by the porosity in a narrow sense, but controlled by the porosity in a broad sense, including the fine fractures. Especially, when considering the flow of the low viscosity coefficient of the high temperature boiling water, even a small cracks can not be disregarded. For instance, at the Hachimantai Onuma power plant (Japan), the geothermal fluid is collected from the blocky low porosity formation with well developed small fractures. Granite has very low porosity, but when considering the overall granite body, often times the factures are well developed, and it is difficult to identify it as poor permeability bed at all times. Therefore, it is possible to suppose that the geothermal fluid can be collected from the granite body.

Many surface geothermal indications do not necessary mean that the favorable high temperature fluid reservoir exist at depth. Furthermore, the surface manifestations of the deep geothermal fluid origin may not necessary be connected directly to the center of the high temperature geothermal reservoir.

Therefore, in examining and analyzing the results of the survey, it is necessary to keep aforementioned facts in mind to interpret the survey results properly.

3-5-1 The Geological Structures and Geothermal Fluid System

(1) For the first time the outcrops of the granodiorite basement formations were confirmed.

At the western area of the granite outcrops, although the elevation is low, the granite is not exposed at the surface. Therefore, the Pachamiya River and the western end of the granite outcrops of the Chuyul River were tied to assume as a fault (Fault A). Fault A seems to be a normal fault with the east side relatively elevated.

(2) The lowest formation in this area is the later Cretaceous consisting of perlitic rhyolite lava to form Old Volcan de Zunil Lava formation, and it covers the granodiorite at unconformity.

The geological age of this lava formation is unknown. Again, there is a possibility that a separate formation (especially, on the west bank of the Samala River) may exist below this lava formation.

(3) The stratigraphical sequences after Tertiary is as shown in Fig.

3-1, but the tuffaceous to tuff breccia beds, which was treated as Zunil formation group in the past might be on the top of Cerro El Galapago Lava from the types of breccia included in the beds and the abut structure observed at the outcrops.

As the Zunil formation is the result of deposition in the old canyon of the Samala River, there is a strong possibility that it is an equivalent to the southern end of Cantel formation formed by depositing in Quezaltenango basin.

(4) From this survey the new geothermal indications were discovered in the western area of Line-A with the alteration zone, fumaroles and gushers of hot springs.

The arrangement of the indications runs in a straight line from NE to SW, which was assumed as Fault D.

This fault may possibly be connected to the high geothermal zone below the Zunil Water Fall lava in depths.

The characteristics of the fault is not clear, but in general, if the theory is followed that the bottom of the volcano was elevated, there is a possibility that the west side of the fault is relatively elevated.

(5) Besides, the Faults B, C, E, F, G and H were confirmed or assumed. As the confirmed faults are cutting across the scoria deposits, the fault has been active during the Quaternary.

(6) The types of hot spring water may be classified as HCO_3, SO_4 and NaCl types. HCO_3 type hot spring has a head of about 2,100m elevation and the similar type hot spring gushing at the Samala River bank must be an underflow of the hot spring in the western area of Line-A through alluvial cone and volcanic breccia.

For the future, the geothermal fluid, as an object of the geothermal development, has a head of 1,960m elevation with NaCl type geothermal fluid. Its chemical composition is very similar to many of the high temperature geothermal fluid developed in the past from the geothermal zone at depth.

(7) Excluding the SO_4 type of hot spring water, the concretions are found at the hot spring gushing points. The concretions formed by NaCl type hot springs are siliceous, whereas, the concretion by HCO_3 is calcium carbonate.

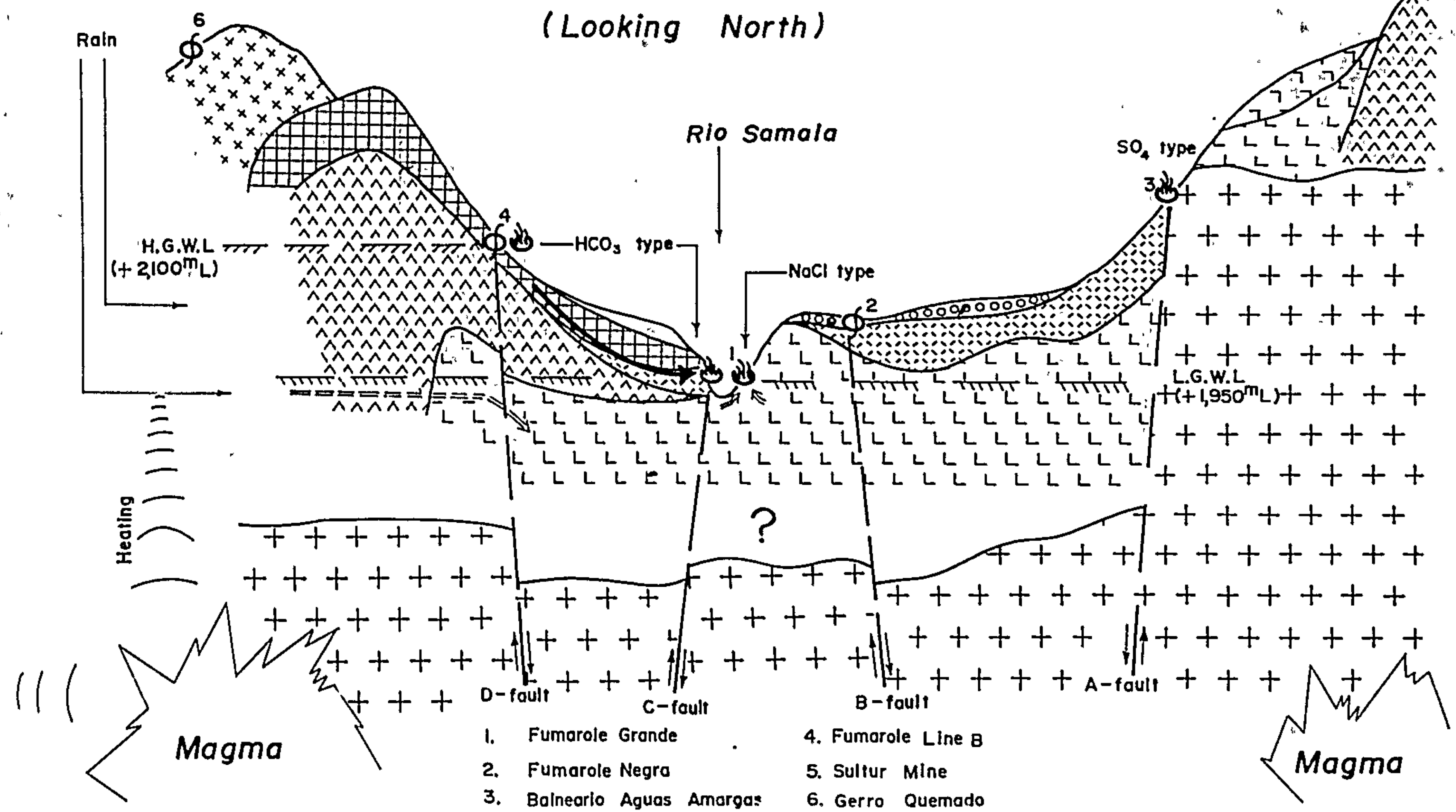
(8) The most of the samples collected from the geothermal alteration zones indicate leaching action of surrounding rocks by acidic water.

(9) The NaCl type geothermal fluid considered as the object of development has a possibility as a reservoir in the aquifer formed by the graben structure enclosed by Faults A and D.

(10) Judging from the general hot spring survey and the topography, the vicinity of Volcan Cerro Quemado-Almolonga, north to northwest of Zunil geothermal area is also considered as one of the most highly potential location for geothermal development.

Fig. 3-8

Ideal Geothermal System of Zunil Geothermal Field
(Looking North)



1. Fumarole Grande
2. Fumarole Negra
3. Balneario Aguas Amargas
4. Fumarole Line B
5. Sulfur Mine
6. Gerro Quemado

H & L.G.W.L. Low and High Ground Water Level

CHAPTER 4

ELECTRICAL SURVEY

CHAPTER 4

ELECTRICAL SURVEY

4-1 Objectives of the Electrical Survey

The objective of the electrical survey is to decide the location of the drilling hole, and interpolate the underground structure in the Zunil geothermal area, by means of collecting the basic information of the geothermal reservoir.

4-2 Method of the Electrical Survey

4-2-1 Principle of the Electrical Method

The electrical method is one of the geophysical methods utilizing the electrical property of rocks. It consists of many types of measuring methods, one of which is resistivity method, wherein the apparent resistivity is measured. From the analysis of the distribution of the resistivity, the underground structure may be assumed. In this, a current (a direct or very low frequency alternating current) is introduced into the ground by two electrodes, and the potential difference is measured between two points suitably chosen with respect to the current electrodes. The two types of electrode configurations which are most frequently used in resistivity sounding are called the Wenner and Schlumberger arrays.

The potential at any point due to a current source at the surface of a homogeneous earth is:

$$V = \frac{\rho I}{2\pi r} \qquad (4\text{-}1)$$

where I is strength of a direct current, ρ is the resistivity, r is the distance between the points of current source and the observation, and V is the potential. When the current I is introduced into the surface of a homogeneous earth, by means of two current electrodes A and B the potential difference between two potential electrodes M and N is given by - using equation (4-1):

$$V = \frac{\rho I}{2\pi}\left\{\left(\frac{1}{AM} - \frac{1}{BM}\right) - \left(\frac{1}{AN} - \frac{1}{BN}\right)\right\} \quad (4\text{-}2)$$

which gives the resistivity of the ground as follows:

$$\rho = \frac{V}{I} \cdot \frac{2\pi}{\left(\frac{1}{AM} - \frac{1}{BM}\right) - \left(\frac{1}{AN} - \frac{1}{BN}\right)} \quad (4\text{-}3)$$

Various electrode configurations for A, B, M and N have been suggested for the purpose. The Schlumberger and Wenner arrays belong to the symmetrical array.

The Schlumberger array was applied in this survey. In this array, the points A, M, N and B are taken on a straight line such that the points M and N are symmetrically placed about the center O of the AB on the condition of AB $\geq$ 5MN as shown in Fig. 4-1.

The earth consists of various rocks and layers, therefore, the earth is in-homogeneous electrically. For such in-homogeneous earth, if the apparent resistivity ρ_a is used, it can be treated similarly as the observed data in a homogeneous earth. It is a function of the resistivities and the thickness of layers, and the electrode distance.

The apparent resistivity is calculated by the same equation (4-3) as a homogeneous earth, using ρ_a instead of ρ. On the Schlumberger electrodes array, the apparent resistivity observed at electrode distance of AB corresponds to one at the depth of AB/2.

When the current electrode distance (AB) is short, the current flows in the shallower part of the earth so that the apparent resistivity shows the resistivity near the surface. But, if AB is enlarged the current flows in the deeper part of the earth, then the apparent resistvity become to show the resistivity of the deeper layer (Fig. 4-1).

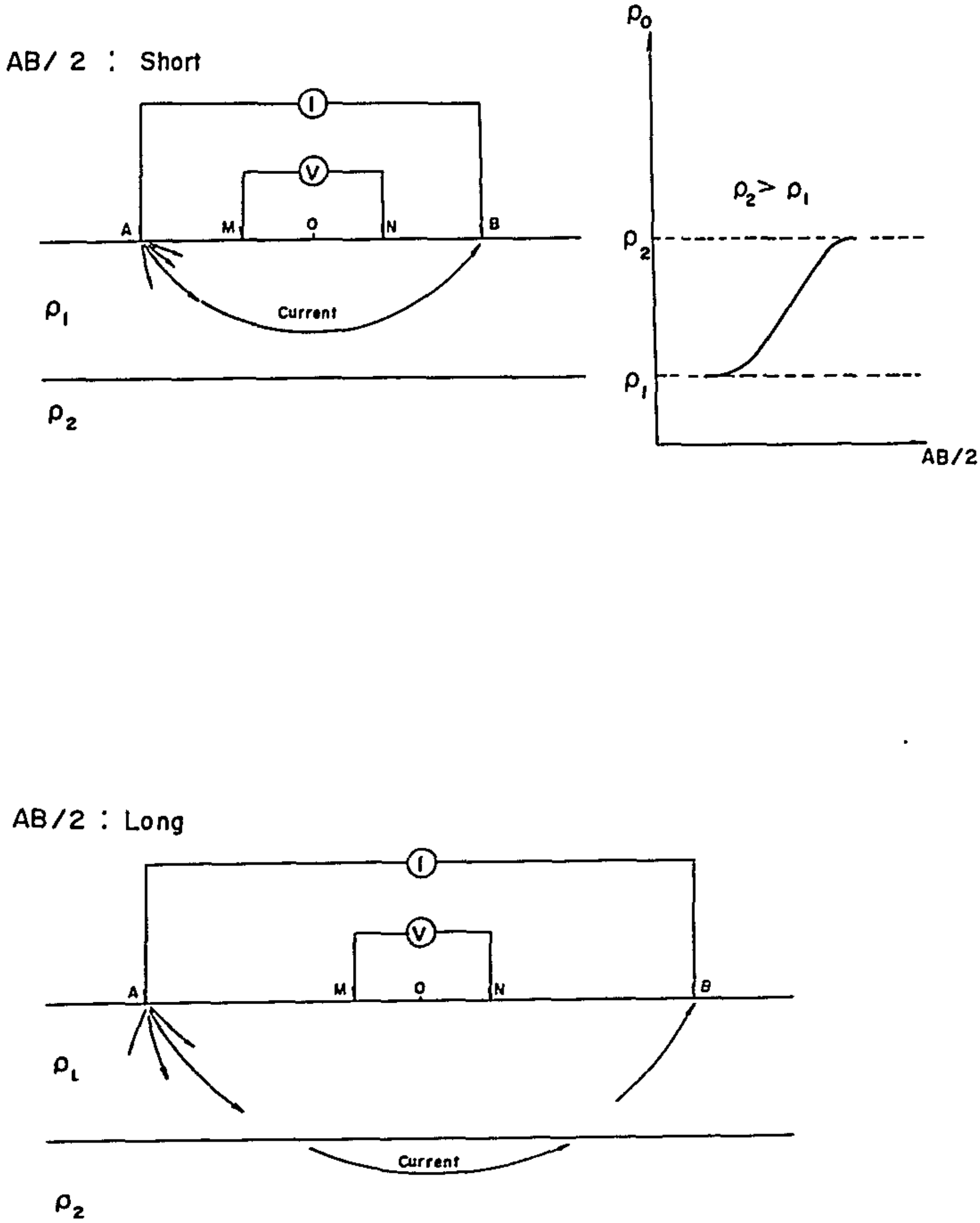


Fig. 4 - 1 Schulumberger Array

4-2-2 Specification

This survey was carried out by the following specifications.

Method	Resistivity method using the Schlumberger electrodes array
Electrode Distance	Current electrodes (AB/2); 10 - 1,250m Potential electrodes (MN/2); 2 - 100m
Current	Constant current of 0.1 Hz square wave (0.1 - 0.5A)
Current electrodes	Three stainless steel rods with the diameter of 3cm and the length of 110cm, or eight stainless steel rods with the diameter of 0.5cm and the length of 80cm, were used. At the place of high ground resistance, the efforts were made to lower the resistance by pouring salt water into the ground surface.
Potential electrodes	Porous pot (non-polarizing electrodes of Cu and a solution of $CuSO_4$)
Wire	Vinyle covered piano wires were used. At the transmitter side, two rolls of wire were placed, and the measurements were taken by extending these wires to A and B.

4-2-3 Instruments

Instruments used in this survey and their specifications are as follows (Fig. 4-2):

Transmitter System:

Transmitter	Mitsubishi type power generator Model CH-509 A, B (made by Chiba Electric Laboratory,

	Japan)	
	Out put Voltage	200 - 800 V
	Out put current	Constant current of 0.1,
	0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 and 2.5 A (nine steps)	
	Stability of constant current less than ± 0.5%	
	Frequency	0.1 Hz (square wave)
Engine generator	Model 13032 (made by Geotronics Inc. U.S.A.)	
	Maximum power 2 KW (115 V. 17.3 A, 400 Hz)	

Receiver System:

Pen Recorder	Pen Recorder Model EPR-200A (made by Toa Electronics Co., Ltd., Japan)	
	Range	± 1 mV - 200 V (16 steps)
	Input impedance	2 M Ω
	Chart speed	5 - 320 mm/min (13 steps)
	Power	9 V dc

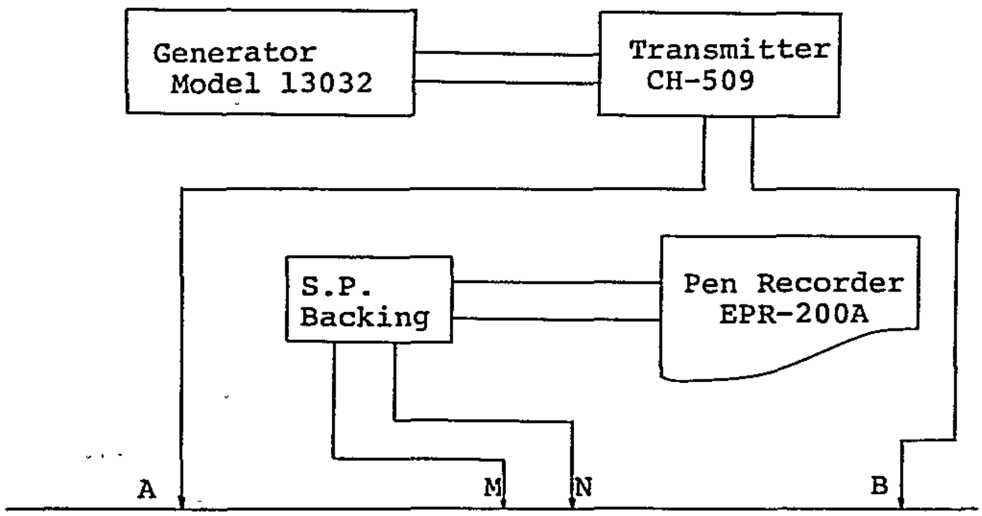


Fig. 4-2 Observed System

4-2-4 Measuring Line

Length and number of center points of each measuring lines are as follows (Fig. 4-3):

Line	Length (m)	Number of center points
Line-1	2,900	9
Line-2	2,950	8
Line-3	3,200	7
Line-4	2,950	6
Total	12,000	30

Line-1 is a line running in NE-SW direction on the west side of the survey area, and coincides with Line-A of the seismic survey.

Line-2 is a line running from the north-east side of the survey area, towards No. 69 of Line-1.

Line-3 is a line running through the central part of the survey area in the direction from the west to the east, and coincides with Line-B and C of the seismic survey.

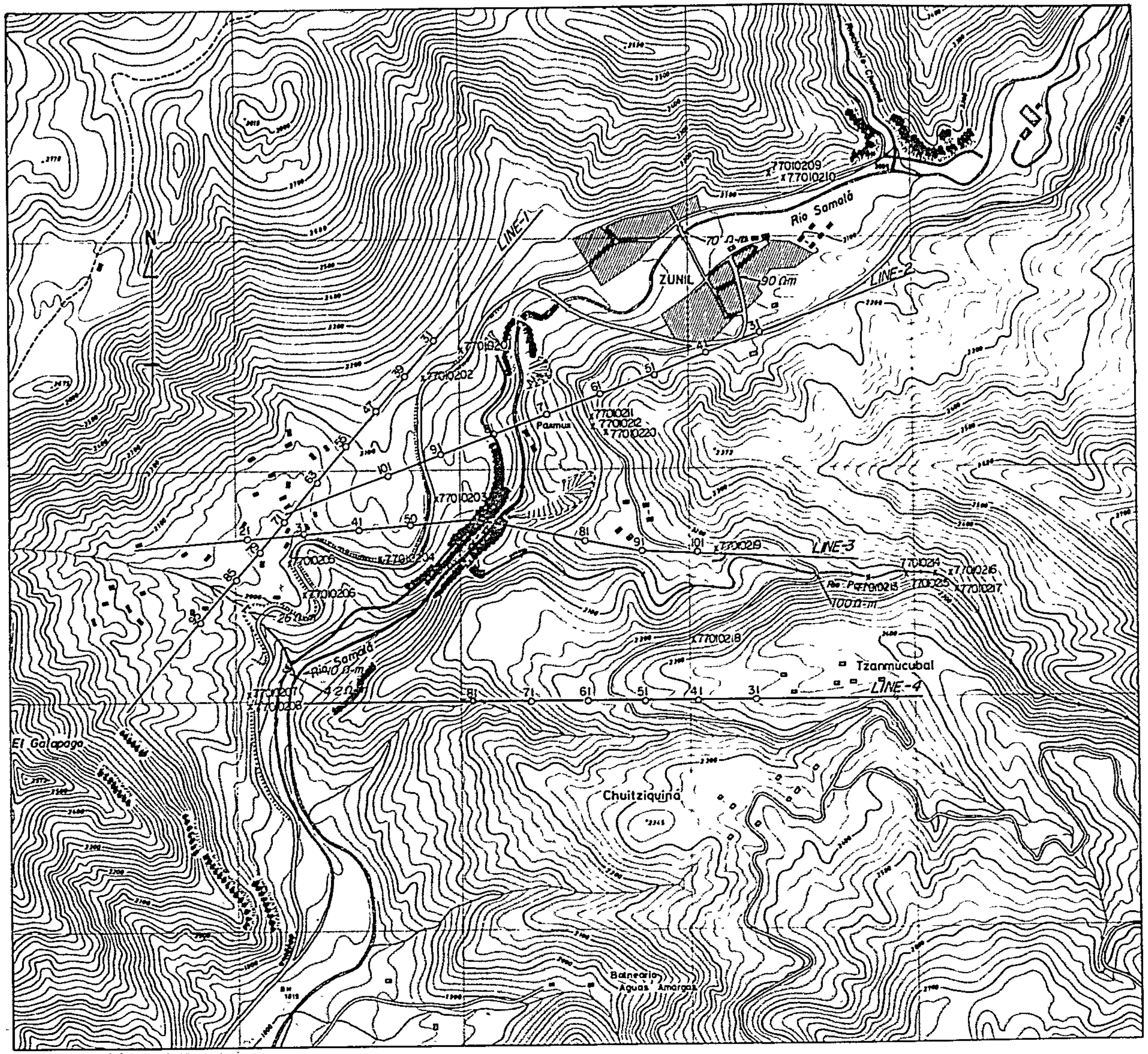
Line-4 is a line running through the south side of the survey area, in the direction from the east to the west.

The distances between center points were 250m, as a rule, but 200m was used for Line-1.

4-3 Method of Analysis

4-3-1 VES (Vertical Electric Sounding) Analysis

The potential waves observed by means of the pen recorder were recorded through the self potential compensation circuit. As a rule, the potential wave forms are a superimposition of potentials of self potentials, telluric current, electro-magnetic coupling,



LEGEND

- Center Points
- 75 Ω-m — Water Resistivity
- Hot Spring
- x — Collected Point of Rock Sample

Geothermal Power Development Project in Zunil, the Republic of Guatemala

LOCATION MAP

(Electrical Survey)

1 : 20,000

400m 0 600m

DEC. 1976 JAN. 1977 Fig. 4-3

current ripples, noises of power generation and electrical short-circuit, besides the signals.

In this survey, comparatively satisfactory wave forms were obtained as a whole. But, when AB/2 became longer, the signal wave were often disturbanced by the effect of the telluric earth current, etc. so that the signal to noise ratio (S/N) became low. For these disturbance waves, the waves were read at several points so that the potential differences were calculated.

The apparent resistivity is calculated, using the potential difference V and the current I observed, as follows:

$$\rho_a = K \frac{V}{I} \quad (\Omega m)$$

K is the geometrical factor having the dimension of the length(m). The value of the apparent resistivity is checked by means of plotting the apparent resistivity vs. AB/2 on a double logarithmic graph. If the values were not as expected, the measurements should be repeated. VES curves at each observation points are obtained by repeating the above-mentioned procedure.

VES curves obtained are often different from the theoretical curves, due to the effects of the topography and the local distribution of the high or low resistivity, etc. Using the method mentioned in 4-3-2, only the effect of the topography is corrected quantitatively.

The smoothed VES curves are derived by experimental and qualitative corrections, after quantitative terrain corrections are made. The analysis is made by superimposing VES curve with the theoretical curves, that is, Schlumberger's standard curves of two layers and/or three layers, and auxiliary curve, assuming a horizontally stratified structure (Fig. 4-4).

4-3-2 Terrain Correction

The analysis for the VES curve was made on the assumption that the measurements are made on a flat plane of semi-infinite horizontal multi-layers. But, in the mountain area, the distortion of the potential distribution can be easily seen on the VES curves, due to the effect of the topography, etc.. Therefore, the analysis should be made after the reduction of these distortions.

For the methods of the correction, there are three dimentional computation using the electronic computer, and two dimentional computations using the network of resistance and conductive paper (anacon paper), etc..

For this survey, the method using anacon paper was applied. In this method, it was assumed that the measurements are conducted on the surface of homogeneous earth, and only the terrain effect causes the potential distortion on the VES curves. ρo is the apparent resistivity measured on the anacon paper at the similar electrode array as the measurements at site. And ρc is the apparent resistivity measured on the shortened topographic section at the similar electrode array. Then, C is calculated as follows:

$$C = \frac{\rho_o}{\rho_c}$$

C is regarded as the first approximated coefficient for terrain correction, and it is called as the "terrain correction factor". If the terrain correction factor at each center point is calculated, terrain corrected apparent resistivity ρoa can be obtained, from the apparent resistivity ρa as observed in the survey and above-mentioned factor, as follows:

$$\rho_{oa} = C \times \rho_a = \frac{\rho_o}{\rho_c} \times \rho_a$$

By means of matching the VES curve made by plotting ρoa vs. AB/2 on a double logarythmic graph with the theoretical curves, the

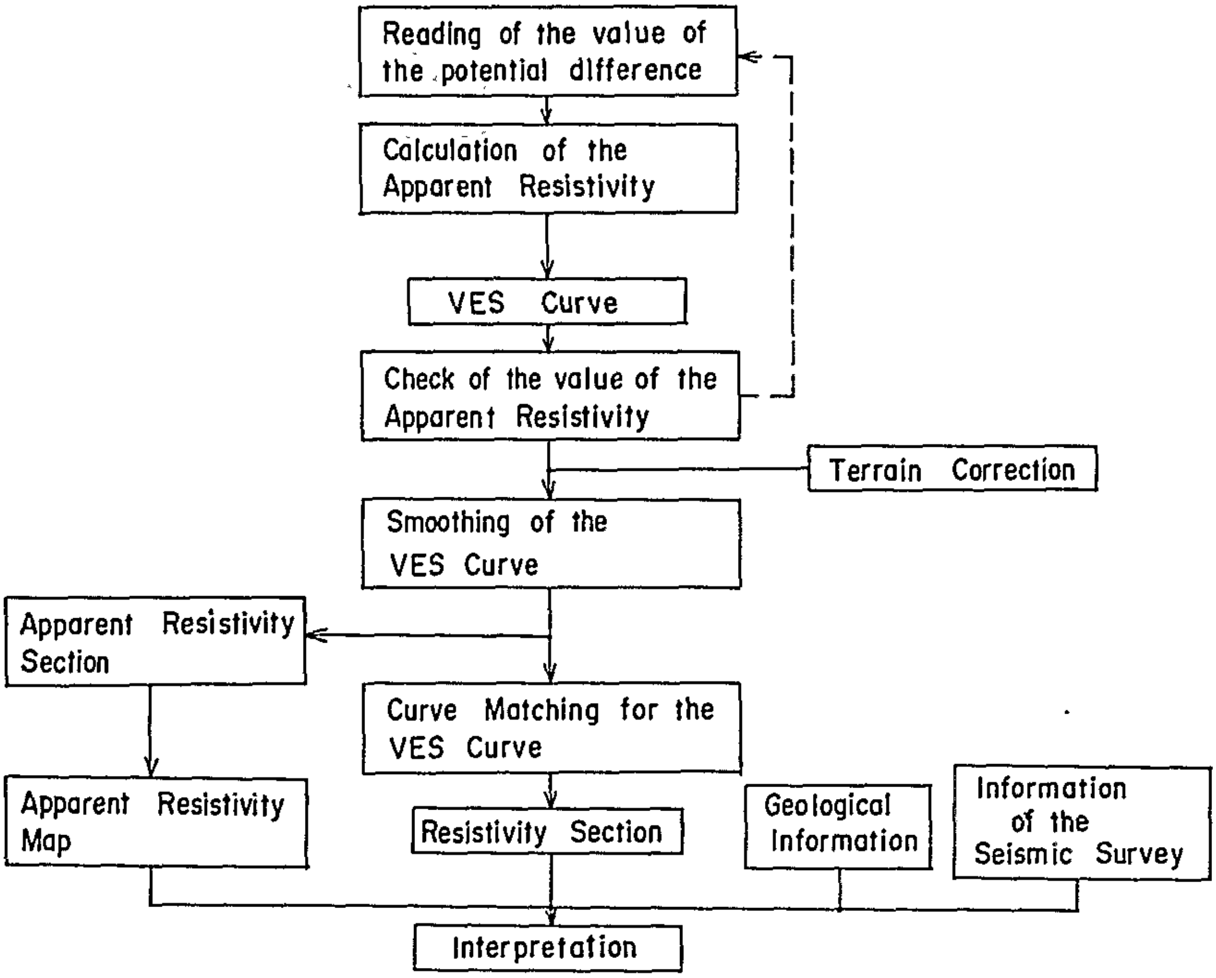


Fig. 4-4 Flow Chart for Analysis of the Electrical Survey

resistivity and the thickness of each layer was estimated.

Anacon paper used for the terrain correction in this survey, is made by Tomoegawa Paper Co., Ltd., Japan. The paper has a dimension of 50cm by 90cm with a thickness of 0.35mm, and the resistivity of about 3 Ω m.

4-4 Measurements of the Electrical Property

4-4-1 Measurements of the Resistivity of the Water

Resistivities of hot spring water, underground water and river water were measured at seven stations in the survey area by means of the Conductivity Meter CM-3M made by TOA Electronics Co., Japan. The Measured locations are as shown in Fig. 4-3 and the results are as follows:

No. 1	Hot-spring water	10 Ω m (Balneario Fuentes Geoginas ref. Fig. 3-4-1)
No. 2	River water	100 Ω m (the Pachamiya River)
No. 3	Underground water	90 Ω m (the Zunil village)
No. 4	River water	70 Ω m (the Samala River)
No. 5	River water	26 Ω m
No. 6	Hot-spring water	4.2 Ω m (the west bank of the Samala River)
No. 7	River water	10 Ω m (the Samala River)

The tendency of the resistivity of the water is as follows:

(1) The resistivities of the hot-spring water (No. 1 and 6) are lower than 10 Ω m, and, if the temperature becomes higher, the resistivity becomes lower because of higher ion activity.

(2) The resistivities of the river and the underground water are higher than 70 Ω m. But the resistivity at No. 7 is 10 Ω m. It may be caused by the inflow of the hot-spring water into the Samala River.

(3) On the basis of the results of the analysis, if there is a layer having the resistivity lower than several Ω m, it may contain a hot-spring water or the geothermal fluid of high temperature.

4-4-2 Measurements of the Resistivity of the Rock Samples

Twenty-one rock samples were collected at the site on the ground surface, as shown in Fig. 4-3. The resistivities of these rock samples were measured by means of a device for measuring the resistivity of rock sample. The results are shown in the Table 4-1. The results of the observations are as follows:

(1) The resistivities of the andesites have large differences as a whole. But the results by the classification of each lava are;

1) The values of the resistivity of samples belonging to Zunil Water Fall Lava have large deviation. In these samples, the resistivity of sample No. 77010203 is low (64 Ω m) because it was sampled near the small fumarole. The deviations of the resistivities of other samples (77010201, 02 and 04) may be caused by the differences of weathering.

2) The values of the resistivity of samples belonging to Almolonga Lava (77010206, 07, 08, 09 and 10) have a slight deviation, except for 77010207 and 08 (81 and 48 Ω m). These low resistivity samples No. 77010207 and 08, may be due to the differences of the weathering sampling points.

3) The values of the resistivity of samples belonging to Pachamiya Lava (77010214 and 17) have the highest resistivity of all

Table 4-1 RESISTIVITIES AND ROCK SAMPLES

Sample No.	Rock Name	Formation	Resistivity(Ωm)
77010201	Andesite	Zunil Water-Fall Lava	205
77010202	Andesite	Zunil Water-Fall Lava	1,307
77010203	Andesite	Zunil Water-Fall Lava	64
77010204	Andesite	Zunil Water-Fall Lava	879
77010206	Andesite	Almolonga Lava	196
77010207	Andesite	Almolonga Lava	81
77010208	Andesite	Almolonga Lava	48
77010209	Andesite	Almolonga Lava	338
77010210	Andesite	Almolonga Lava	270
77010214	Andesite	Pachamiya Lava	1,163
77010217	Andesite	Pachamiya Lava	2,296
77010211	Rhyolite	Old Volcan de Zunil Lava	256
77010212	Rhyolite	Old Volcan de Zunil Lava	237
77010213	Rhyolite	Old Volcan de Zunil Lava	598
77010215	Rhyolite	Old Volcan de Zunil Lava	26
77010218	Rhyolite	Old Volcan de Zunil Lava	200
77010220	Rhyolite	Old Volcan de Zunil Lava	220
77010205	Rhyolitic Breccia	Zunil formation	183
77010219	Tuff	Zunil formation	286
77010216	Granodiorite	Basement rocks	326
77010225	Granodiorite	Basement rocks	596

the sampled rocks.

(2) The resistivities of rhyolite belonging to Old Volcan de Zunil Lava have a little deviation except for 77010215 (26 Ω m).

(3) The arrangement of the resistivity of the formation and/or lavas from the highest to the low is as follows:

1. Pachamiya Lava
2. Zunil Water Fall Lava
3. Granodiorite
4. Old Volcan de Zunil Lava
5. Almolonga Lava
6. ZunilFormation

4-5 Results of Analysis

4-5-1 Apparent Resistivity Section

The apparent resistivity section was made by plotting the values of the apparent resistivity measured at a point equal to the depth of AB/2 from the ground surface.

The apparent resistivity is expressed as a function of the resistivities ($\rho_1, \ldots, \rho_n$) and the thickness of multi-layers ($h_1, \ldots, h_n$), and electrode distance. In a mountain area, the apparent resistivity section obtained have often been affected, due to the topography, the formation and/or the local existence of high or low resistivity, so that it does not always reflect the underground (real resistivity) structure. But the tendency of the apparent resistivity seems to reflect the actual resistivity distribution. The disturbances of the iso-apparent resistivity lines in the apparent resistivity section are often caused by the effects of the topography and/or local existence of high or low resistivity in the shallower part. In these cases, the disturbance of the iso-apparent resistivity lines forming an inverted-

V-shaped contour lines converging at 45° angle extending to depth can be seen, so that further analysis is required by studying these effects.

(1) Line-1 (Fig. 4-5-1)

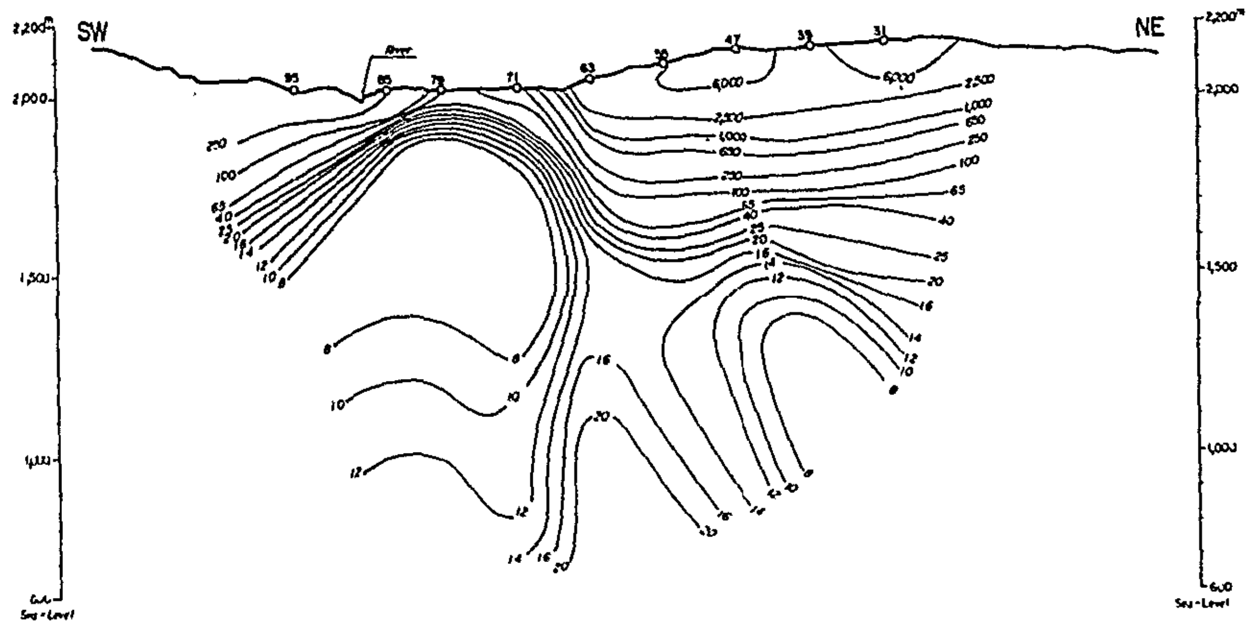
It is estimated that the low resistivity layer may exist through Line-1 Section, but in the northern part of No. 63, its depth may be deeper than in the southern part of No. 63. In the shallower part in the northern part of No. 63, a layer with the resistivity higher than 1,000 Ω m seems to exist and corresponds to the Quarternary lavas.

The inverted V-shaped contour disturbance of iso-apparent resistivity line meeting at 45° angle extending downward, starts to diverge from near No. 71 and No. 79 at the central part of Line-1, which seems to be caused by a low resistivity layer in the shallower part near No. 71 and No. 79.

In the southern part of No. 85, it is estimated that there is a layer with high resistivity of about 200 Ω m in the shallower part.

(2) Line-2 (Fig. 4-5-2)

A layer with low resistivity seems to exist all along Line-2. Its resistivity depends on the location. On the east side of Line-2 at the eastern part of No. 41 the resistivity seems to be higher than in the other parts of Line-2. In the western part of No. 91, there seems to be a layer with the resistivity higher than 1,000 Ω m, corresponding to the Quarternary lavas. A layer with the resistivity ranging from 500 to 1,000 Ω m seems to exist in the shallower horizon near No. 51 and No. 61 at the central part of Line-2, which may correspond to the volcanic rocks, like rhyolite. The cause of the inverted V-shaped disturbance of the



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APPARENT RESISTIVITY SECTION

LINE — I

UNIT IN OHM — METER
DEC. 1976 to JAN. 1977

Fig 4-5-1

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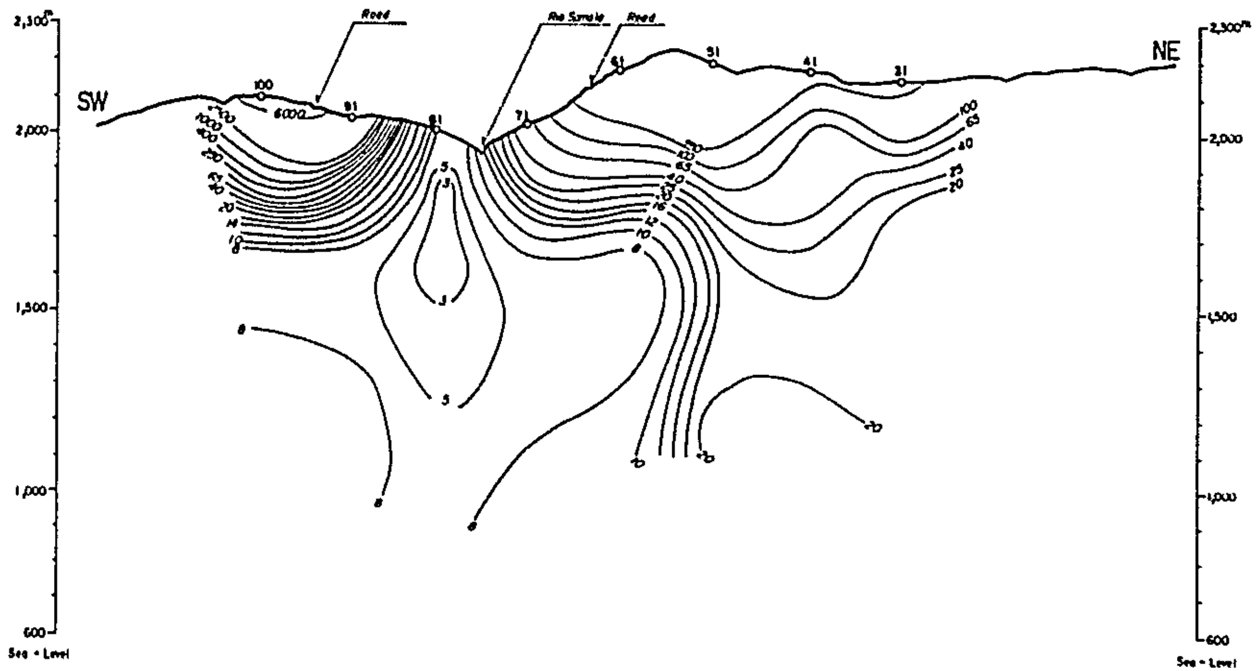
TOKYO, JAPAN



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APPARENT RESISTIVITY SECTION

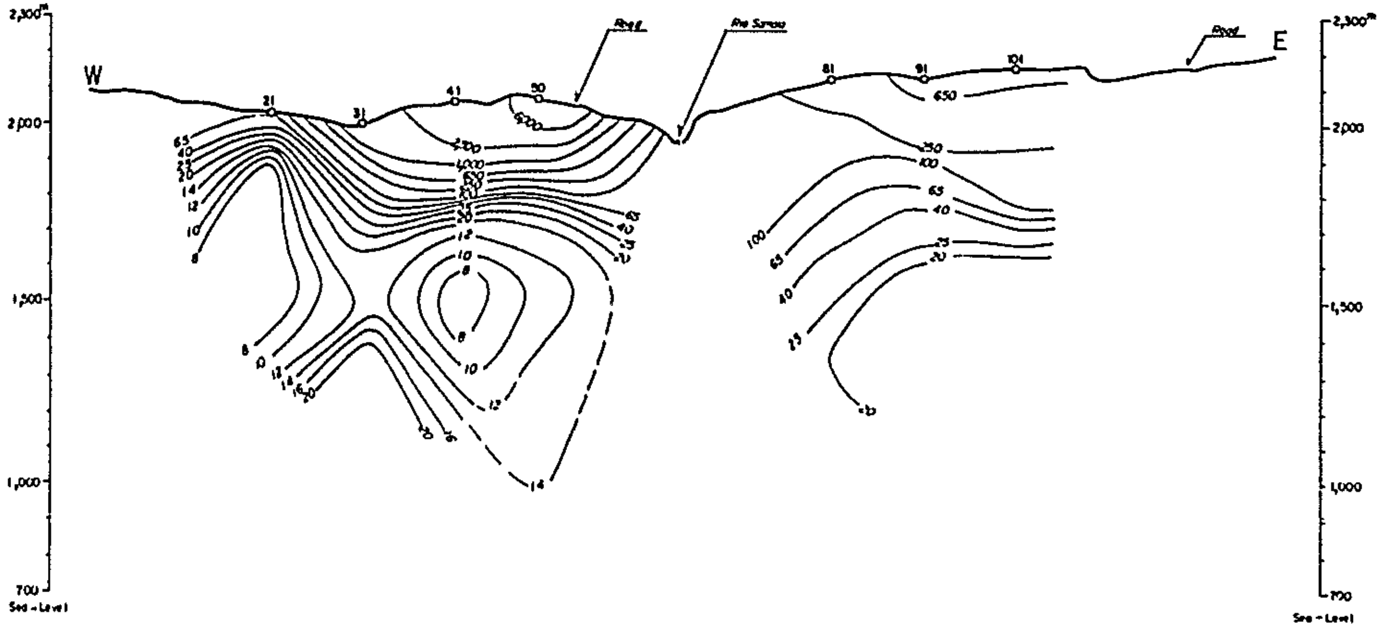
LINE – 2

UNIT IN OHM-METER
DEC. 1976 to JAN 1977

Fig 4-5-2

300m 0 500m

JAPAN INTERNATIONAL COOPERATION AGENCY
TOKYO, JAPAN



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APPARENT RESISTIVITY SECTION

LINE - 3

UNIT IN OHM-METER
DEC. 1976 to JAN. 1977

Fig 4-5-3

300m 0 500m

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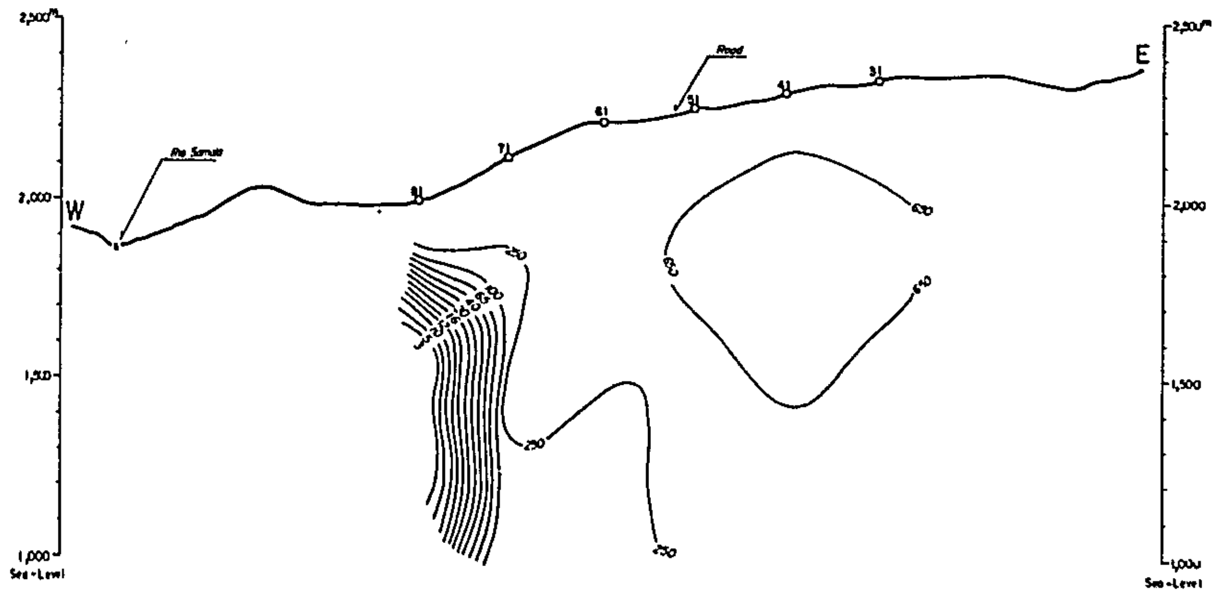

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APPARENT RESISTIVITY SECTION

LINE - 4

UNIT IN OHM-METER
DEC. 1976 to JAN. 1977

Fig 4-5-4

300m 0 500m

JAPAN INTERNATIONAL COOPERATION AGENCY
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contour converging at 45° extending to depth between No. 41 and No. 71 on the east side of Line-2 (the east bank of the Samala River) seems to be due to the existence of a high resistivity layer, as mentioned above.

(3) Line-3 (Fig. 4-5-3)

As the center points could not be set in the central part of Line-3, due to the cliff of the Samala River, it is difficult to discuss the continuation of the underground structure between the east side and the west side of the Samala River.

A layer with the low resistivity may exist all along Line-3. And its resistivity in the west side of the Samala River is lower than in the east side. A layer with the low resistivity in the shallower part of the western part of No. 21, seems to be the cause of the inverted V-shaped disturbance of the contour converging at 45° angle down to the east. In the eastern part of No. 81 and the western part of No. 31, the resistivity structure seems to be considered as stratified from the resistivity point of view.

(4) Line-4 (Fig. 4-5-4)

The pattern of the contour is different between the west end of Line-4 near No. 81 and the east side of No. 71, so that there may be a fault between No. 81 and No. 71.

4-5-2 Apparent Resistivity Map

The resistivity map was made, by means of plotting the positions of the observed points with each apparent resistivity value corresponding to AB/2 of 250, 500 and 750m on the smoothed VES curves.

From the apparent resistivity section, the vertical distribution of resistivity values is given. On the other hand, from a map, the surface variation of resistivity values within a certain depth is given.

The values to be mentioned in the following paragraphs are one of the apparent resistivity at the depth of AB/2 and not one of the resistivity of the layer or rock at that depth.

(1) AB/2 = 250m (Fig. 4-6-1)

The low apparent resistivity zone lower than 20 Ω m can be seen in the areas along the Samala River and near the intersection of Line-1 and 3. And in those areas, there are geothermal manifestations, like, hot-springs and fumaroles etc. The high apparent resistivity zones higher than 40 Ω m almost coincide with the distributions of Zunil Water Fall Lava, Old Volcan de Zunil lava and Zunil Formation.

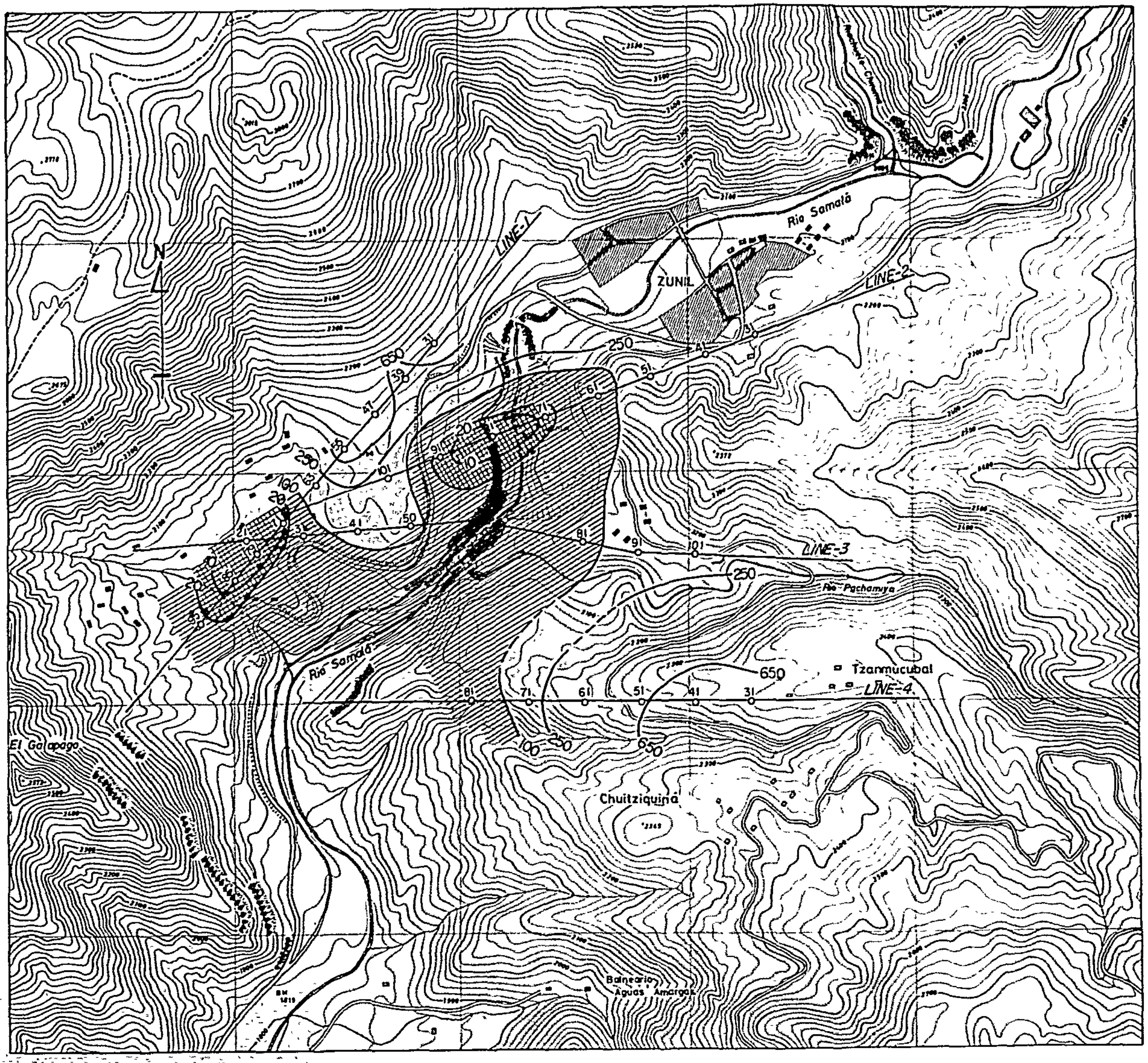
This apparent resistivity map almost coincides with the distribution of the geology on the surface.

(2) AB/2 = 500m (Fig. 4-6-2)

Low apparent resistivity zone lower than 40 Ω m can be seen all over the survey area, except for the area of Line-4 in the southeastern part of the survey area, where there is a high resistivity zone higher than 100 Ω m. The difference of the apparent resistivity distribution between both areas suggests the existence of a fault between Line-3 and 4.

(3) AB/2 = 750m (Fig. 4-6-3)

This map shows the similar distribution of the apparent resistivity in the case of AB/2 = 500m. The existence of the above-mentioned fault is suggested in this case, as in the same manner as AB/2 = 500m.



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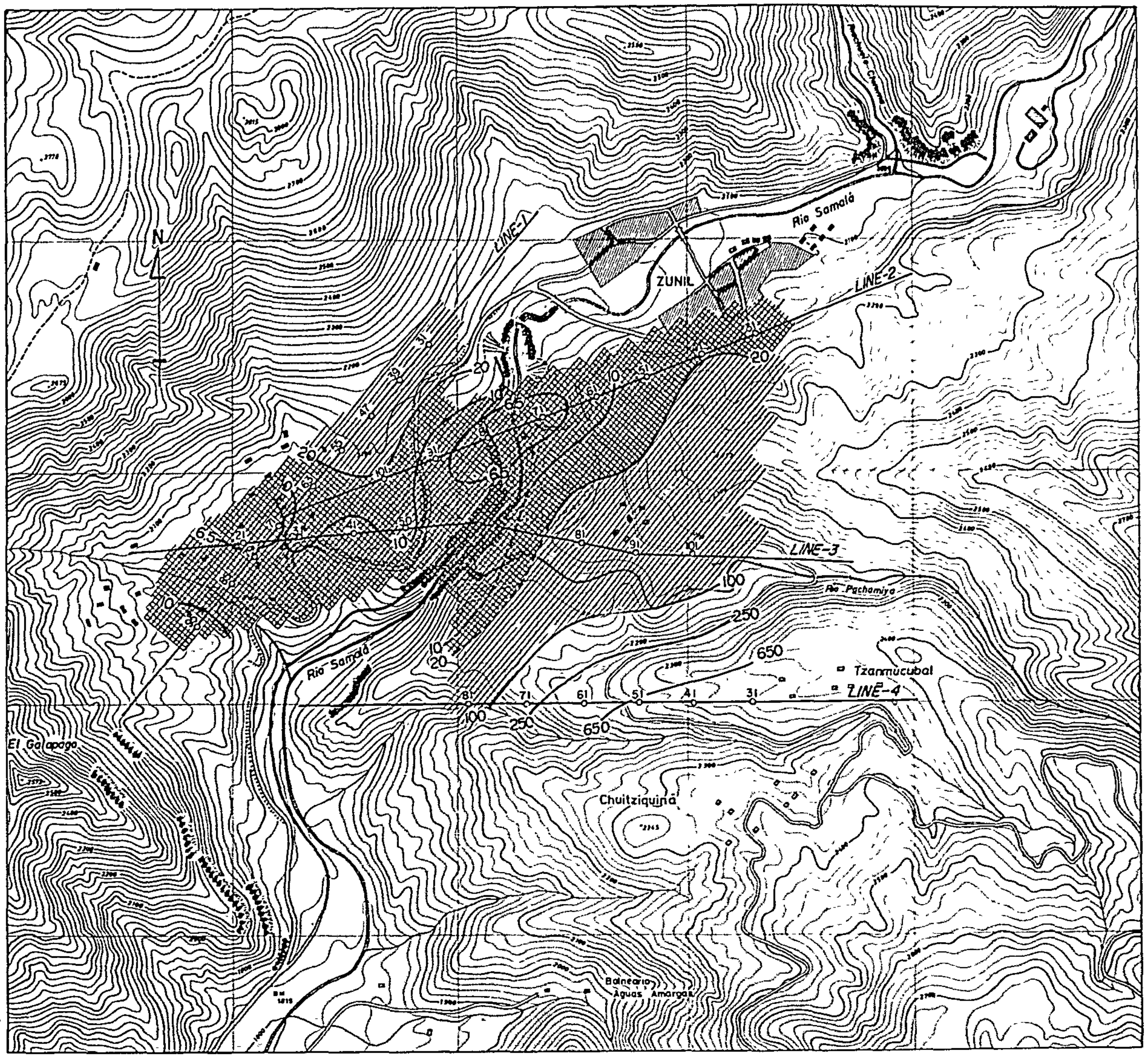
APPARENT RESISTIVITY MAP

AB/2 = 250m

1:20,000

0 — 1,000m

DEC.1976 JAN.1977 **Fig. 4-6-1**



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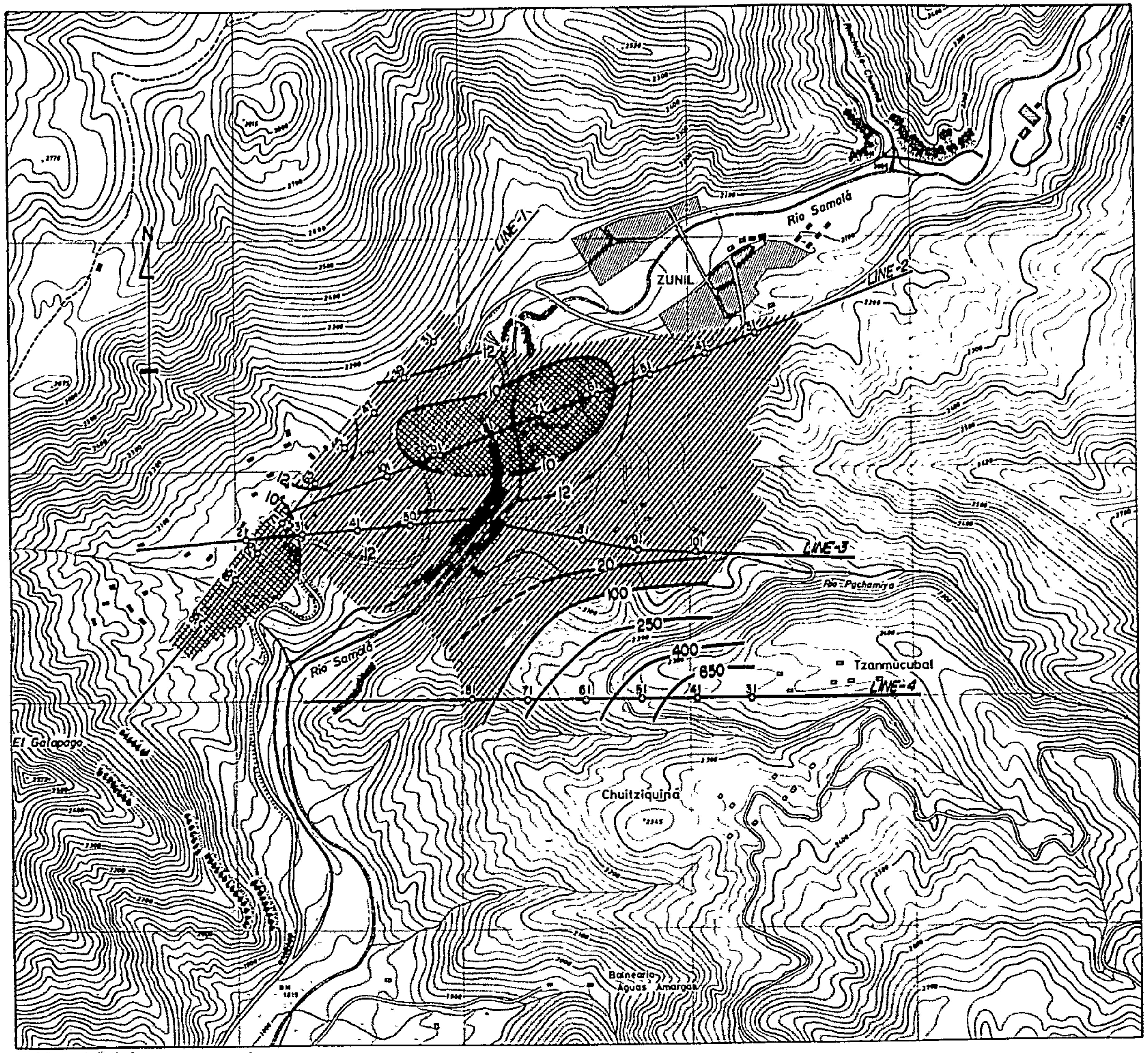
APPARENT RESISTIVITY MAP

AB/2 = 500^{m}

1:20,000

0 1,000^{m}

DEC.1976 JAN.1977 Fig.4-6-2



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APPARENT RESISTIVITY MAP

$AB/2 = 750^m$

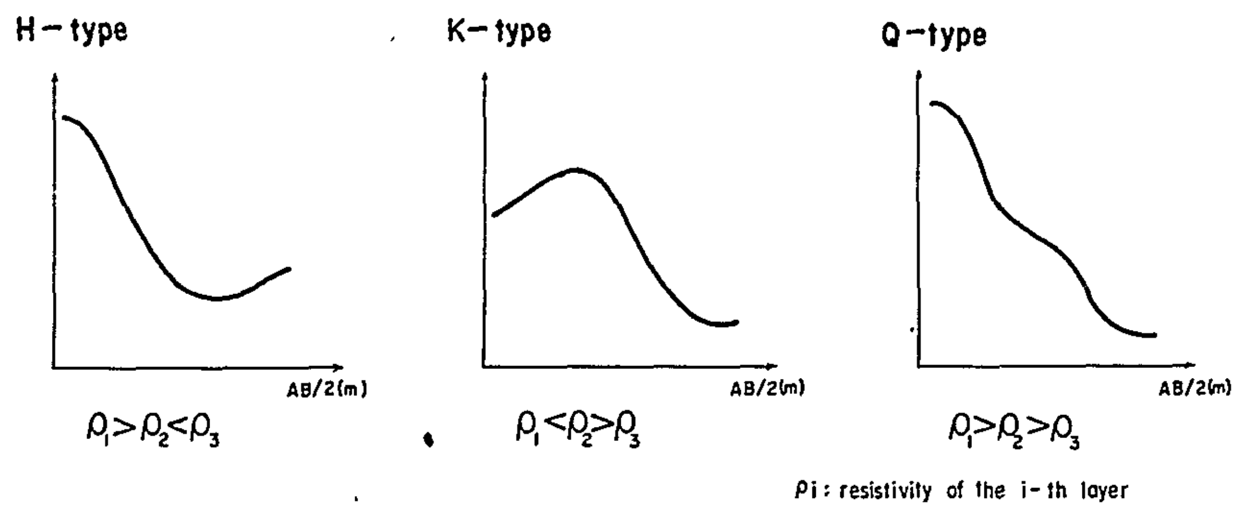
1 : 20,000

0 — 1,000^m

DEC.1976 JAN.1977 **Fig.4-6-3**

4-5-3 VES Curve

The resistivities and thickness of each resistivity layers were estimated, using the curve matching method. From the results of the curve matching, the smoothed VES curves obtained, were classified as H, K, Q and their combined types VES curves and resistivity column sections of 30 center points are shown in Fig. 4-7-1 to 30, and the classification of VES curves is shown in Table 4-2.



Typical VES Curves of Three Layers Type

4-5-4 Resistivity Section

After the estimation of the resistivities and thickness of each resistivity layer from the VES curves at 30 center points, the resistivity sections were made by mean of plotting these values on the topographycal sections.

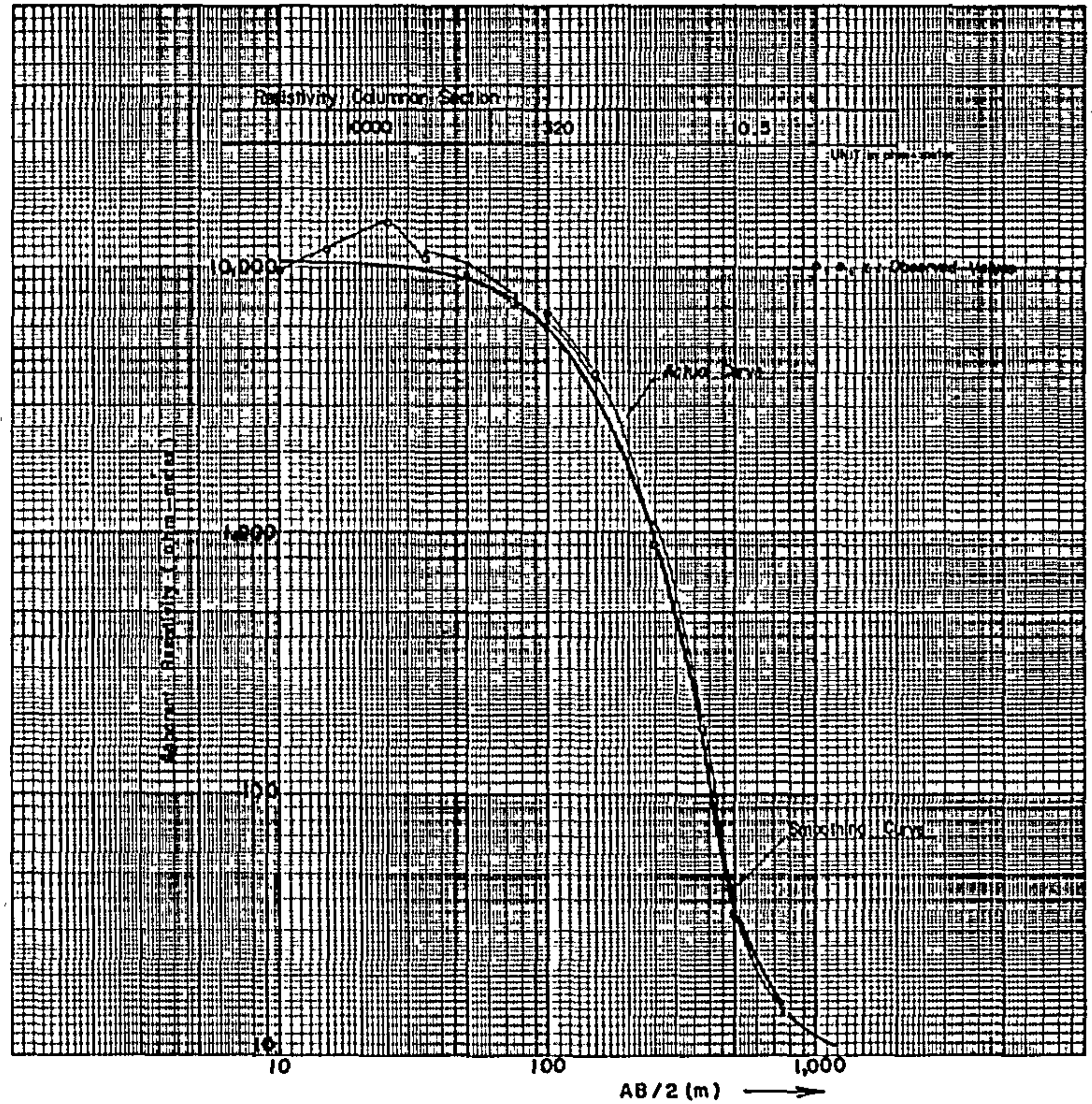
The configuration of the resistivity layers and the fault were assumed from the similarity and differences of the resistivity and thickness between neighboring center points.

Table 4-2 CLASSIFICATION OF VES CURVES

Line	Center Point	Type	Resistivity (Ω m) 1st layer	2nd layer	3rd layer	4th layer	Remark
Line-1	31	Q	10,000	320	11		
	39	QH	7,000	370	11	200	
	47	QH	6,500	370	7.9	150	
	55	QH	9,000	400	10	90	
	63	QH	4,800	320	14	130	←Line-2
	71	QH	120	50	4.5	10	←Line-3
	79	QH	250	35	5.5	10	
	85	H	220		7.3	10	←Valley
	95	KQ	200	35	6.5		
Line-2	31	(2)*	300		16		
	41	Q	400	170	16		
	51	K	130	740	9.0		
	61	KH	130	1,170	4.5	90	←Road
	71	H	50		5.6	20	←Samala River
	81	QH			4.5 ¦ 1.1	20	
	91	H	6,000		4.5	10	
	100	Q	7,000	180	4.5		←Road
Line-3	21	Q	300	35	6.5		←Line-1
	31	H	2,200		8.8	30	
	41	H	9,000		4.0		
	50	H	9,500		12	20	←Samala River
	81	(2)*		200	20		
	91	Q	950	350	12		
	100	Q	1,000	450	12		
Line-4	31	HK	530	130	850	150	
	41	HK	900	180	1,100	280	
	51	HK	590	200	1,800	160	
	61	HK	480	160	720	70	←Road
	71	K		60	1,140	200	
	81	(2)*	1,900		1.7		

* (2) : two layers type VES curve.

— — — : Fault



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VES Curve of LINE-I
Center Point No.31
(Vertical Electrical Sounding Curve)

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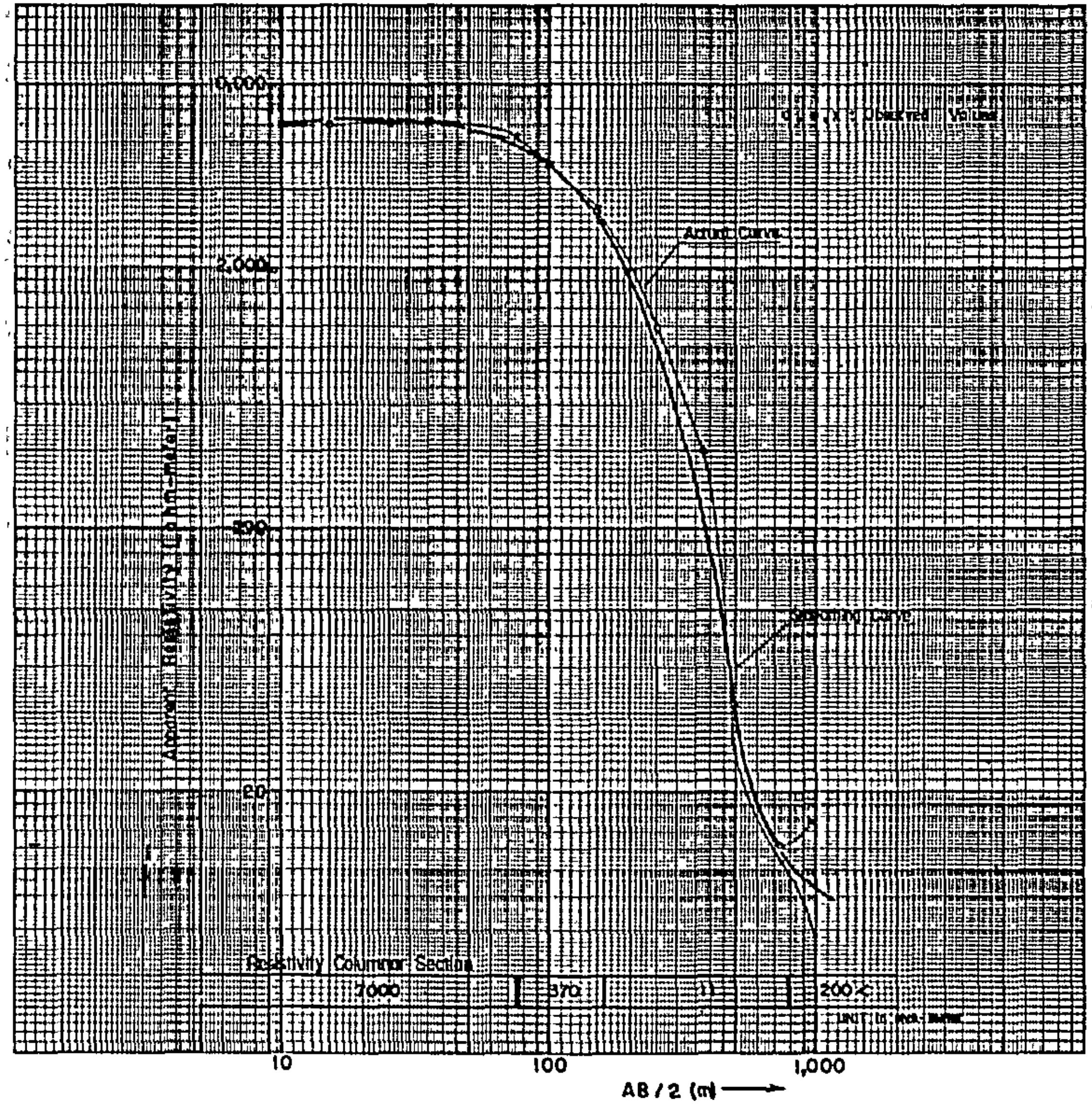
Fig.4-7-1



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VES Curve of LINE - 1
Center Point No.39
(Vertical Electrical Sounding Curve)

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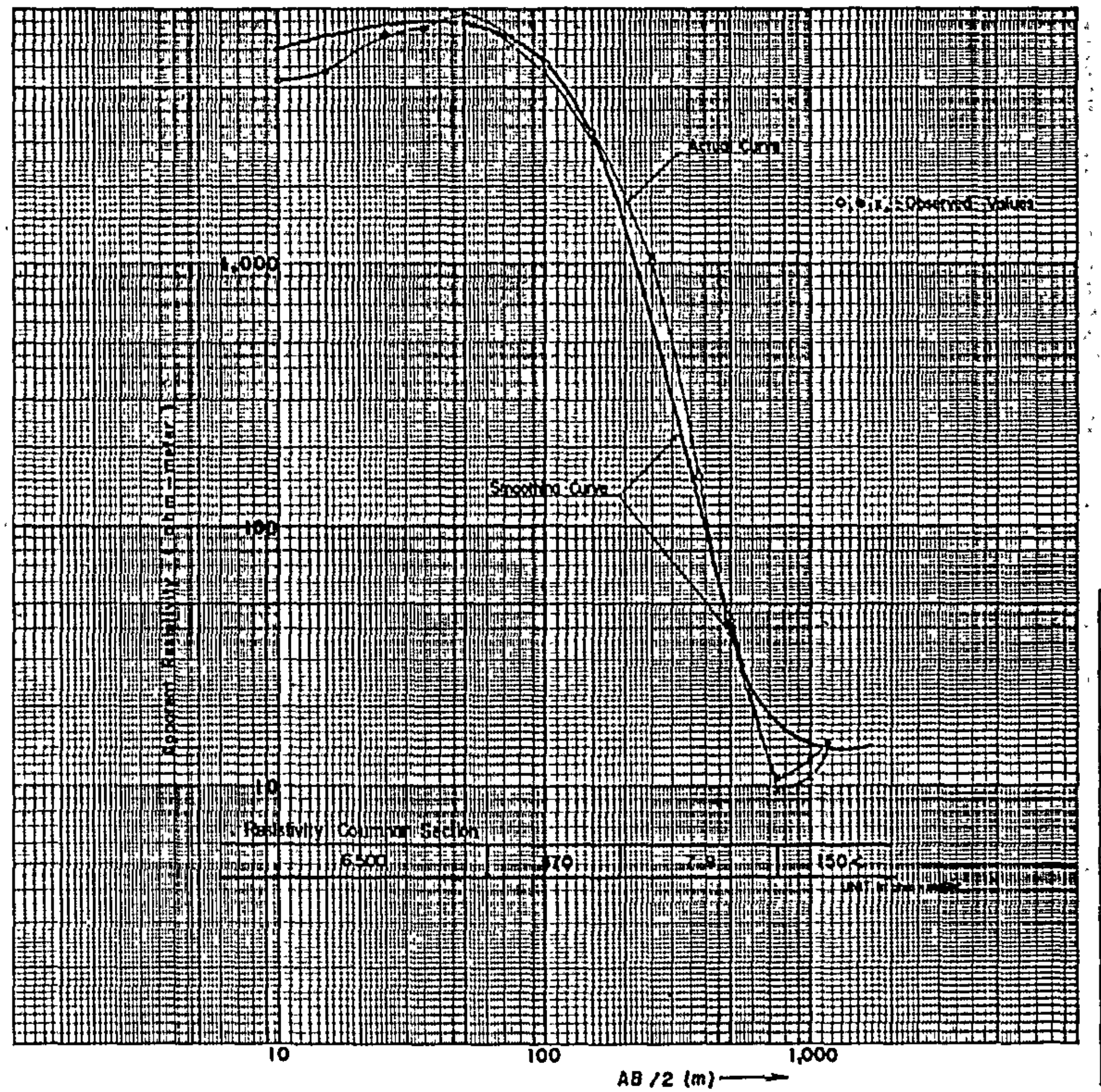
Fig.4-7-2



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VES Curve of LINE - I
Center Point No. 47
(Vertical Electrical Sounding Curve)

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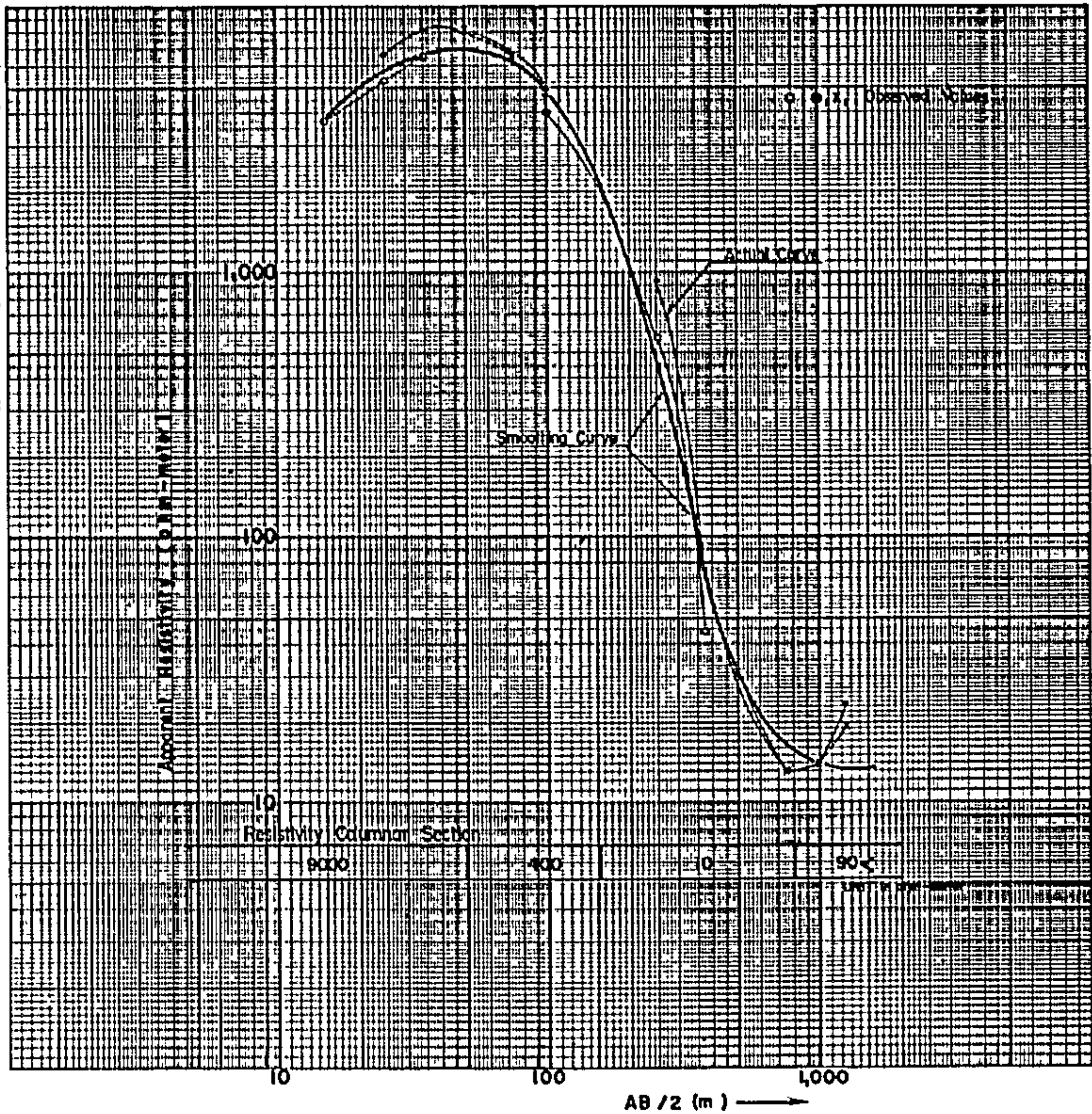
Fig.4-7-3



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VES Curve of LINE-1
Center Point No. 55
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J.I.C.A.)

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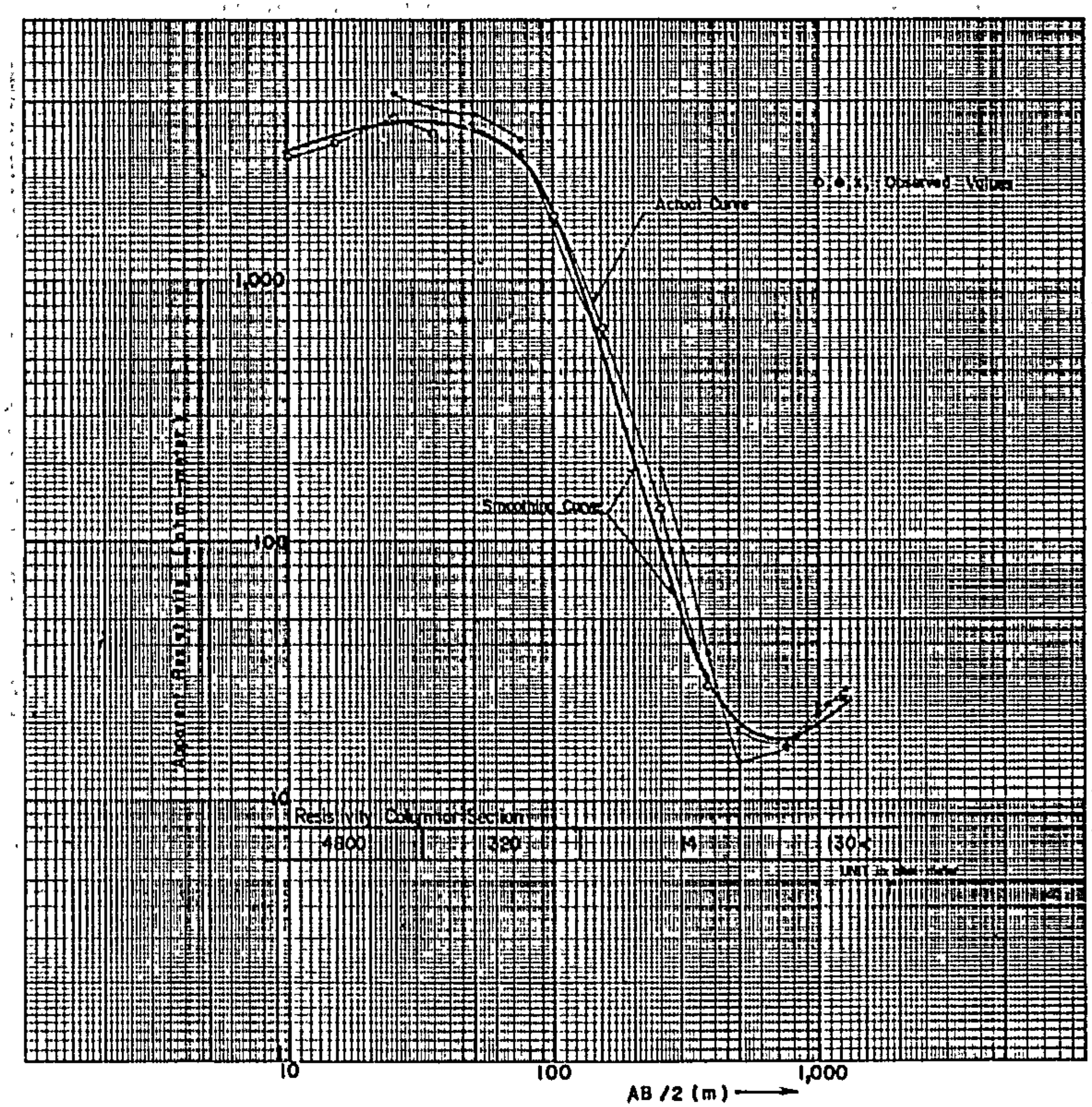
Fig 4-7-4



Geothermal Power Development Project
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VES Curve of LINE - I
Center Point No.63
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
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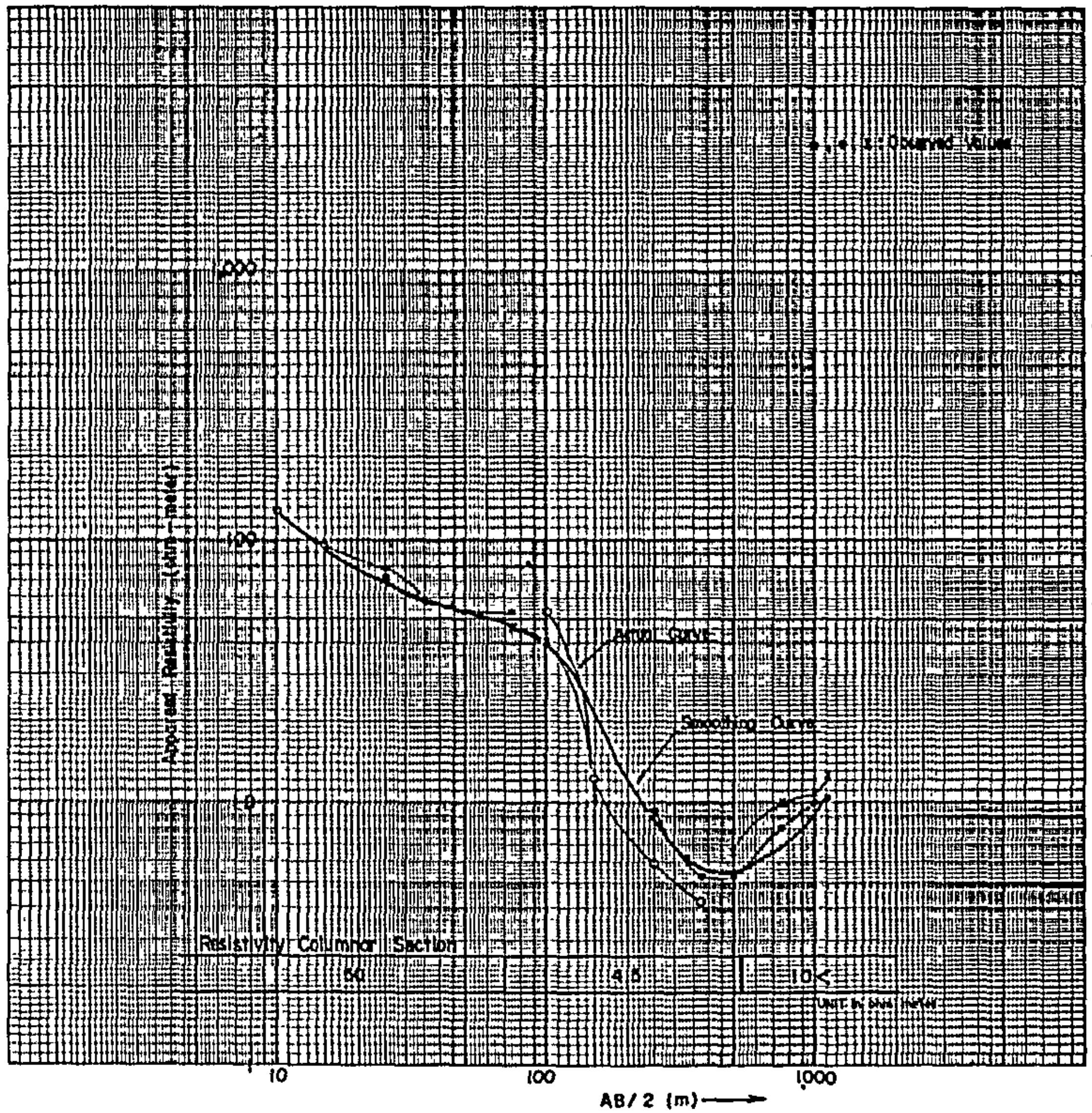
Fig.4-7-5



Geothermal Power Development Project
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VES Curve of LINE – I
Center Point No.71
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
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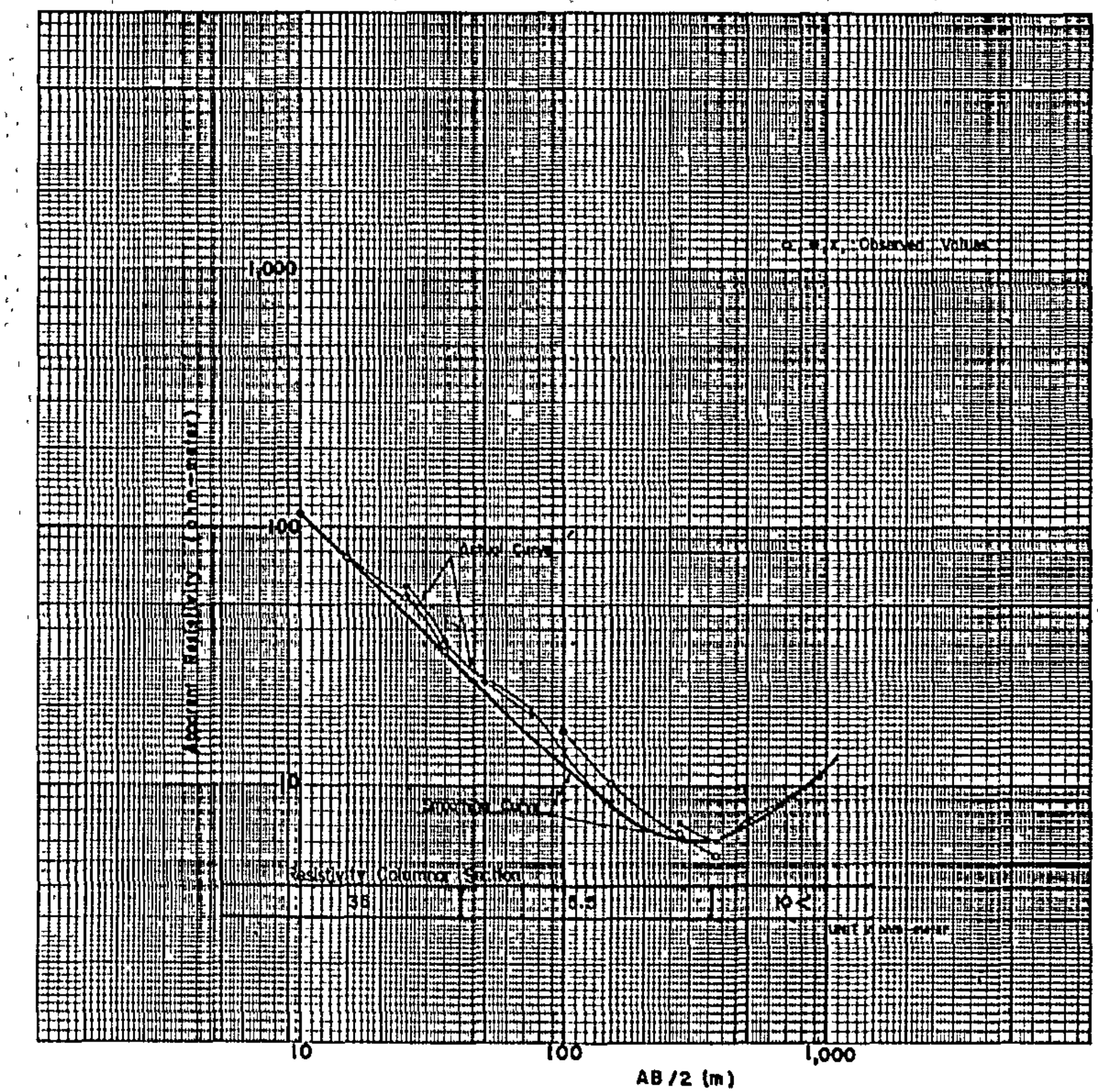
DEC. 1976 – JAN. 1977

Fig.4-7-6



Geothermal Power Development Project
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VES Curve of LINE-I
Center Point No.79
(Vertical Electrical Sounding Curve)

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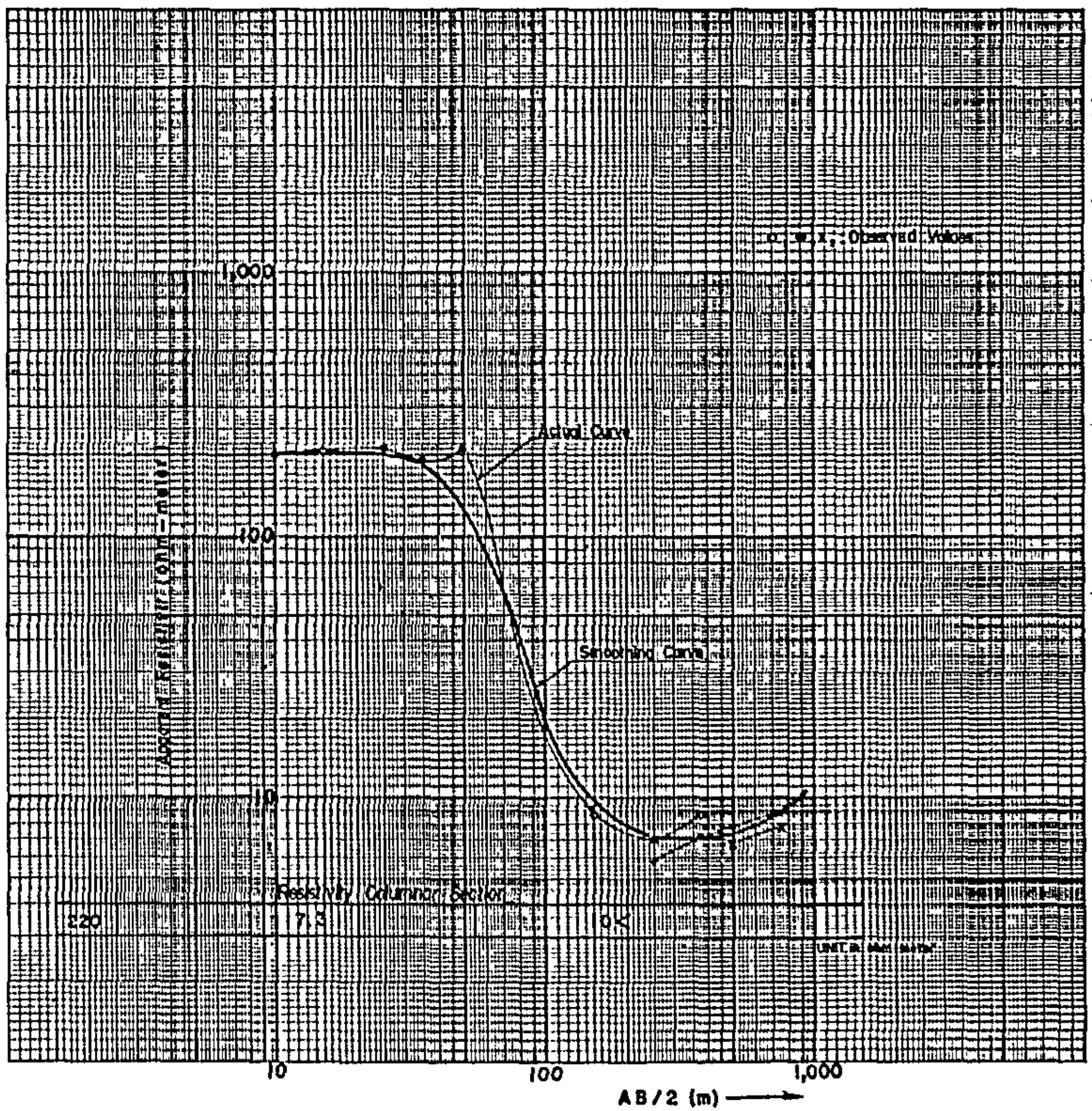
Fig. 4-7-7



Geothermal Power Development Project
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VES Curve of LINE-1
Center Point No.85
(Vertical Electrical Sounding Curve)

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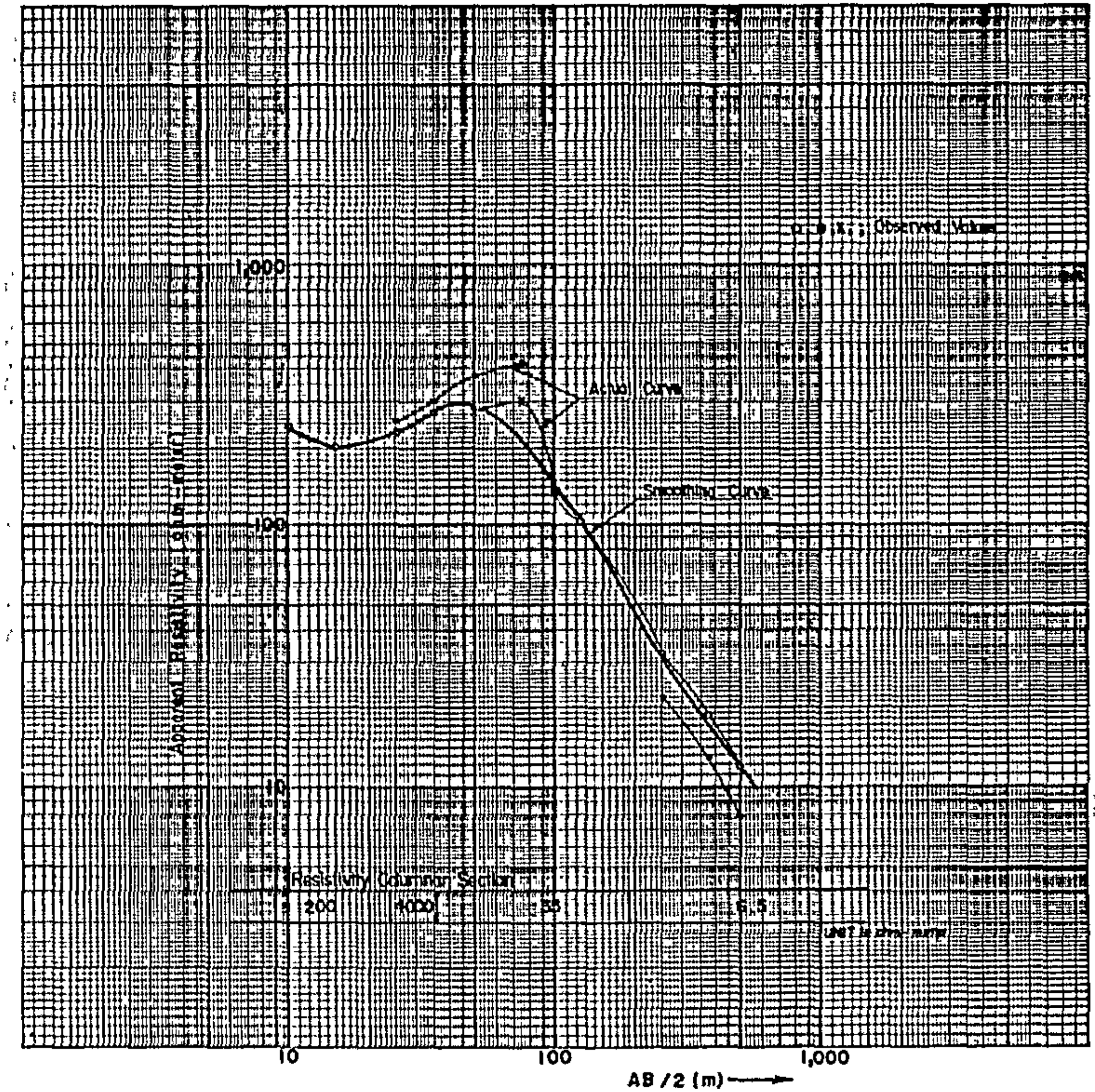
Fig.4-7-8



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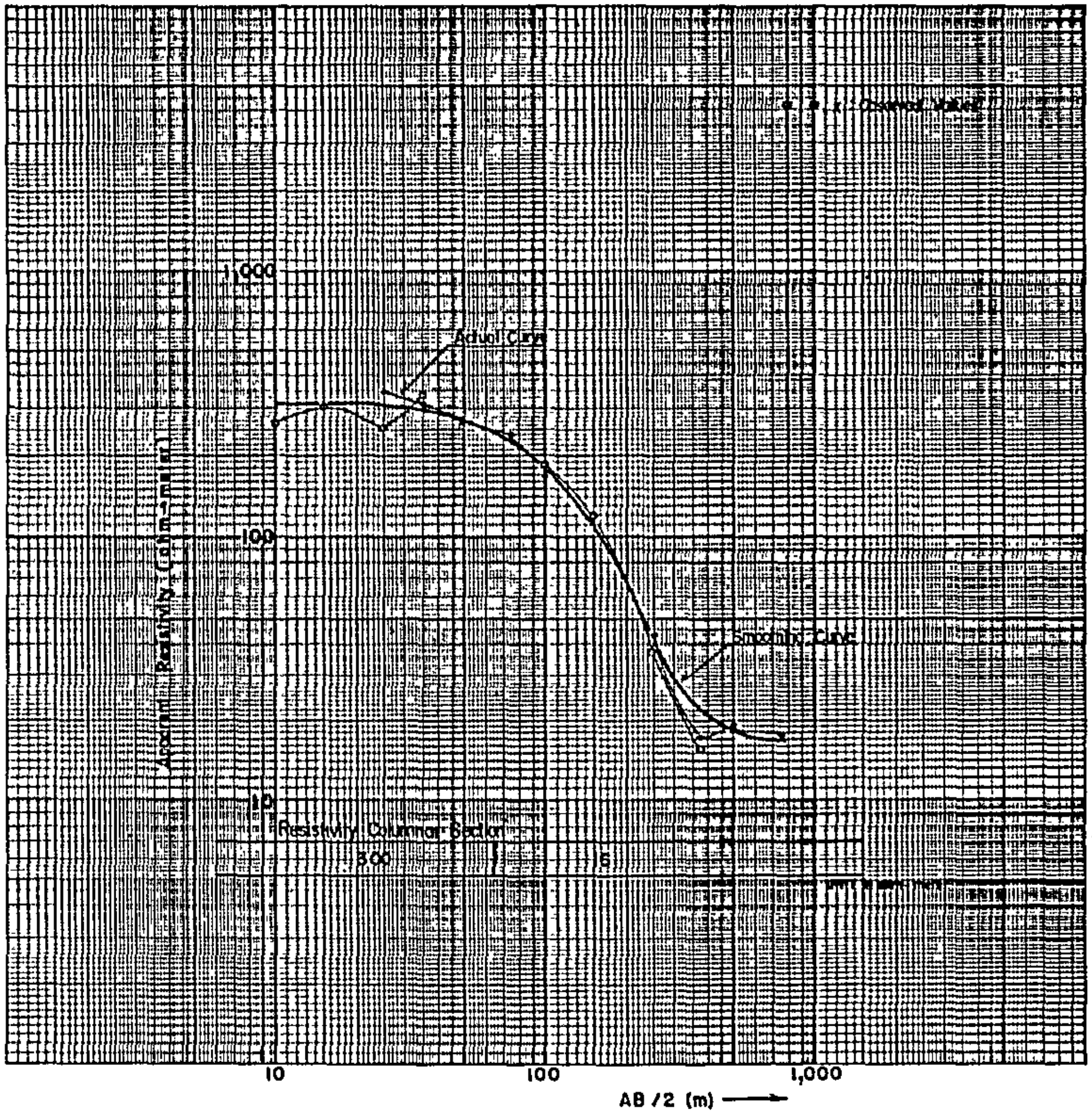
in Zunil,
the Republic of Guatemala

VES Curve of LINE – I
Center Point No.95
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 ~ JAN. 1977

Fig.4-7-9



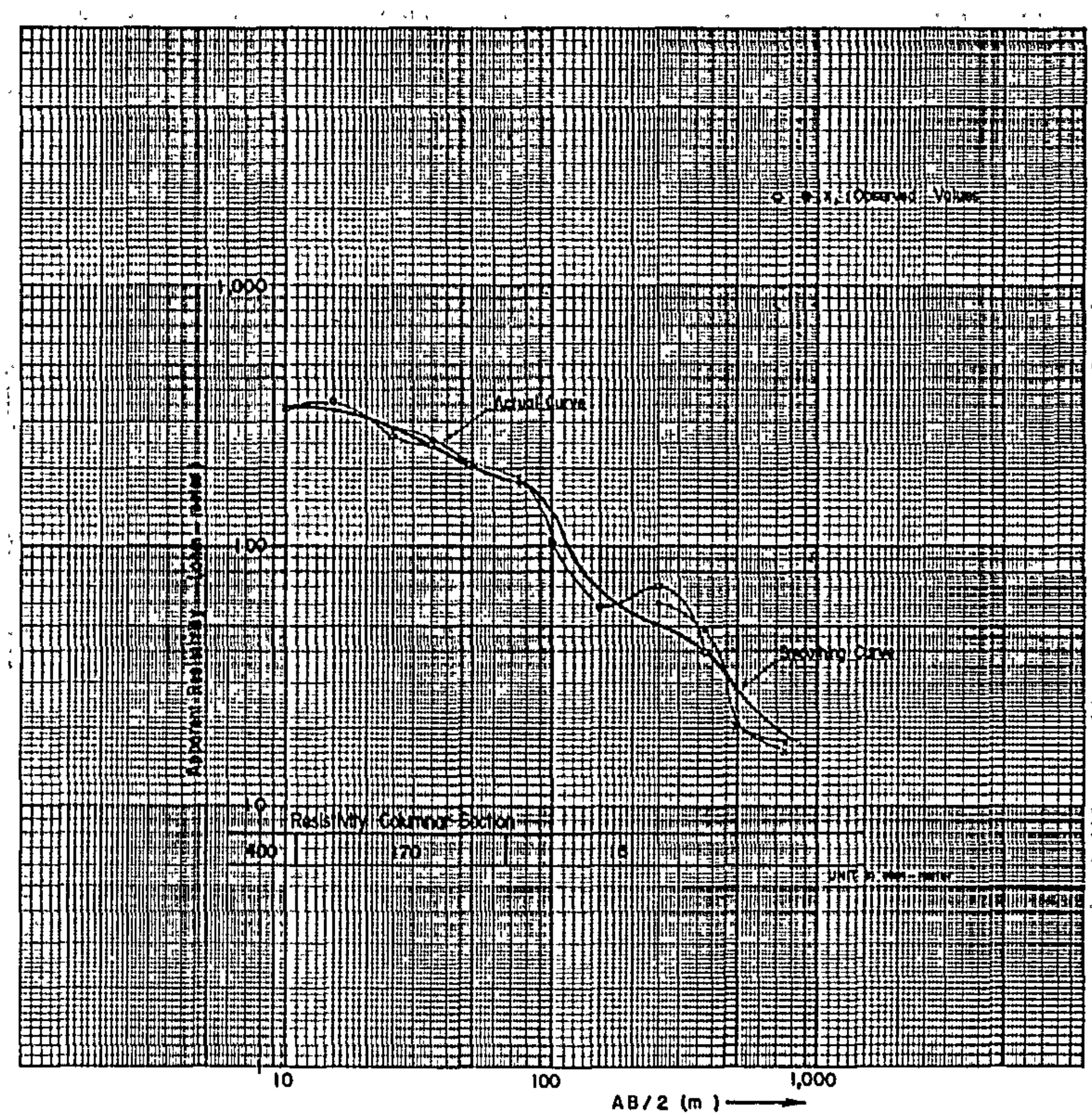
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE - 2
Center Point No.31
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 ~ JAN. 1977

Fig.4-7-10

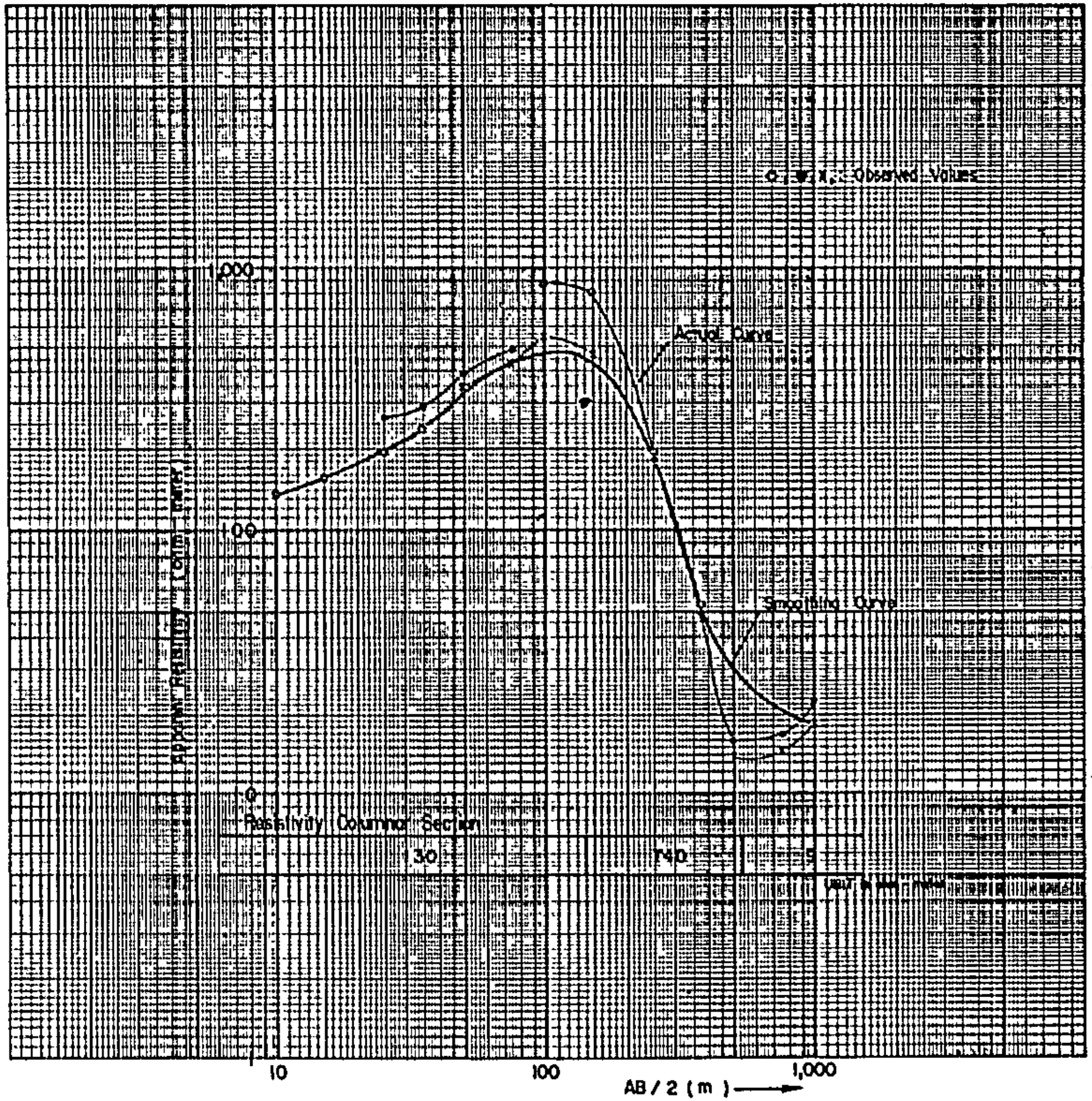


Geothermal Power Development Project
In Zunil,
the Republic of Guatemala

VES Curve of LINE-2
Center Point No.41
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)
DEC 1976 — JAN 1977

Fig.4-7-11



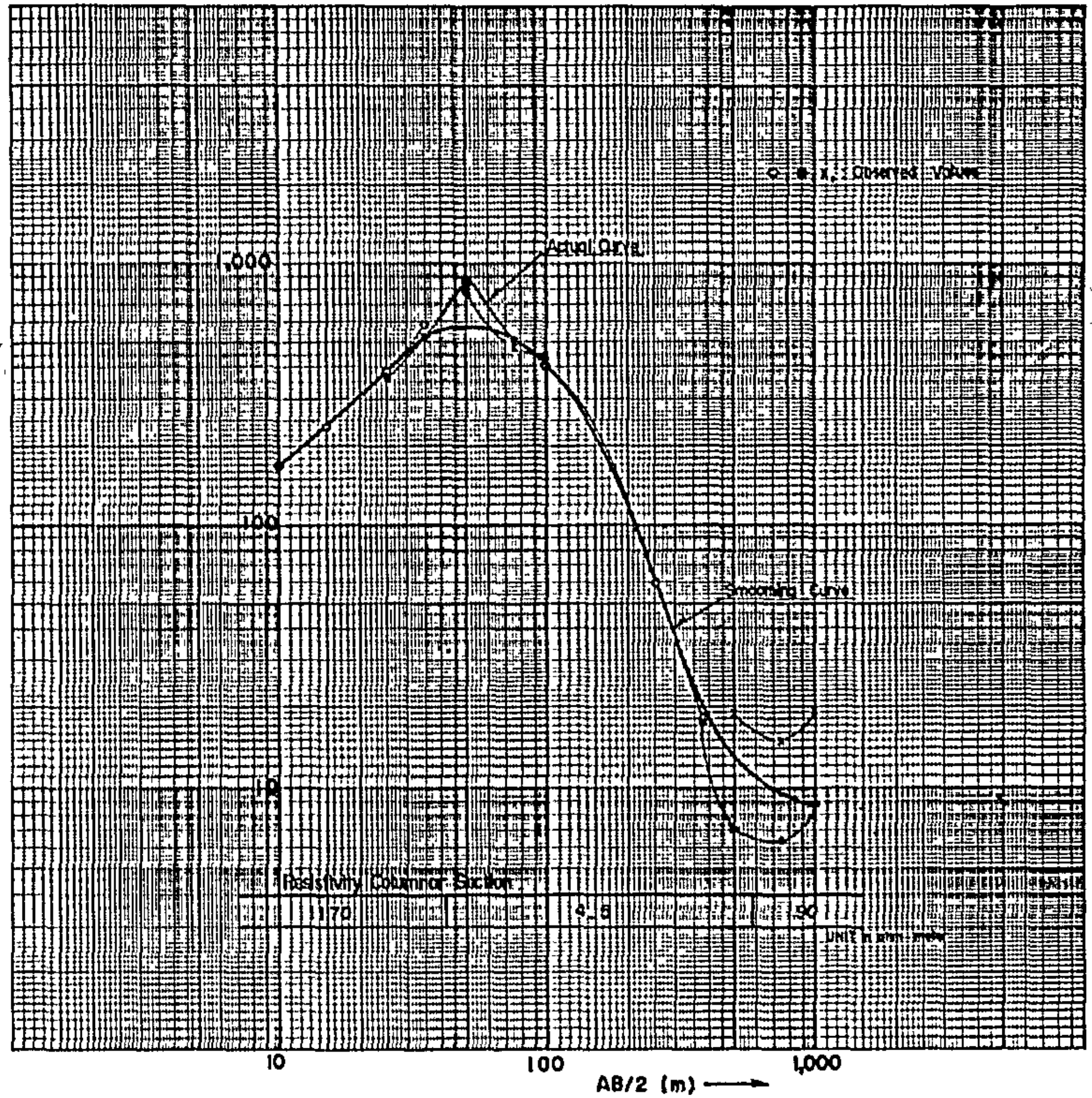
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE – 2
Center Point No. 51
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 ~ JAN. 1977

Fig. 4-7-12



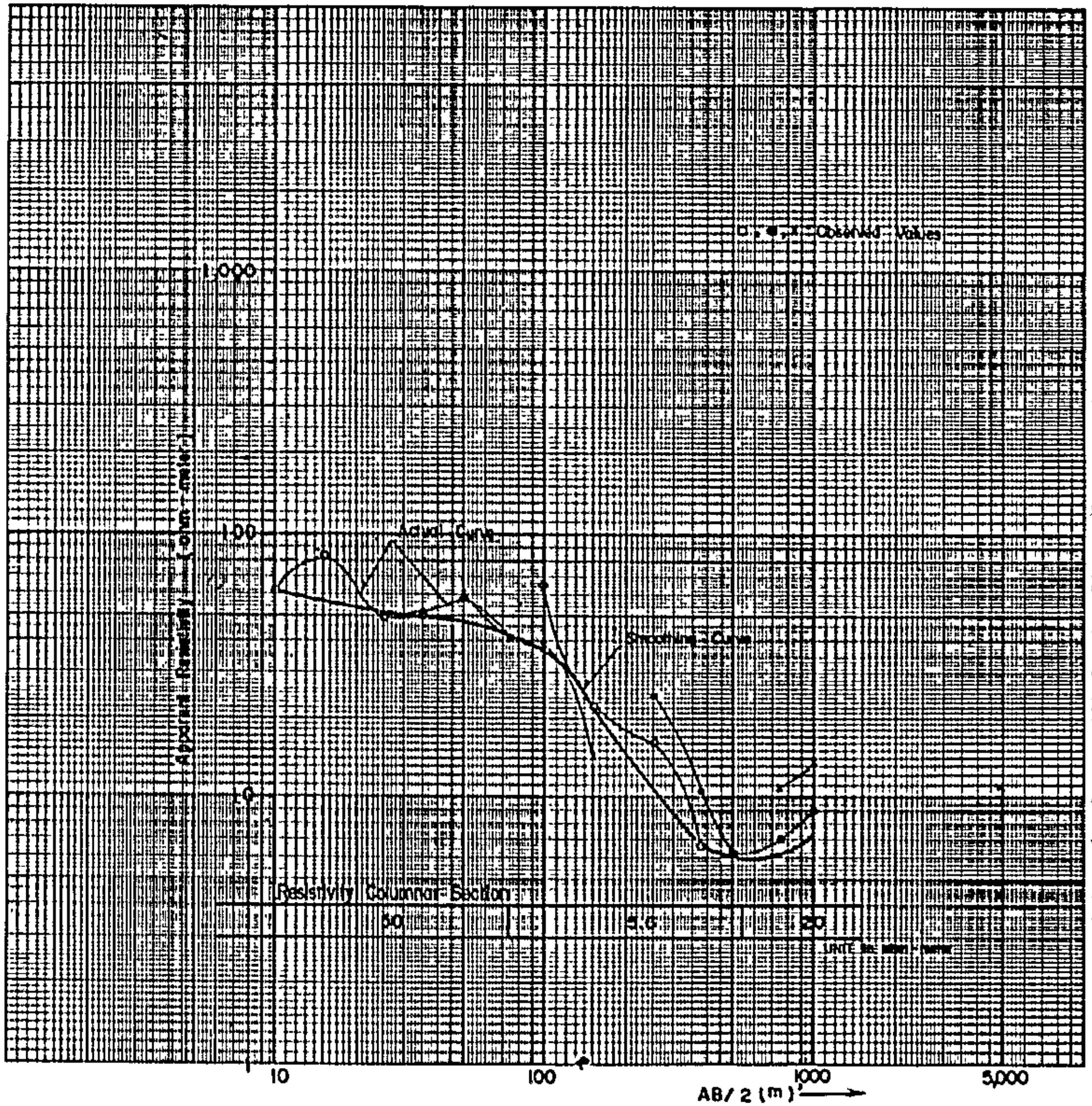
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE-2
Center Point No.61
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J.I.C.A.)

DEC. 1976 ~ JAN. 1977

Fig.4-7-13



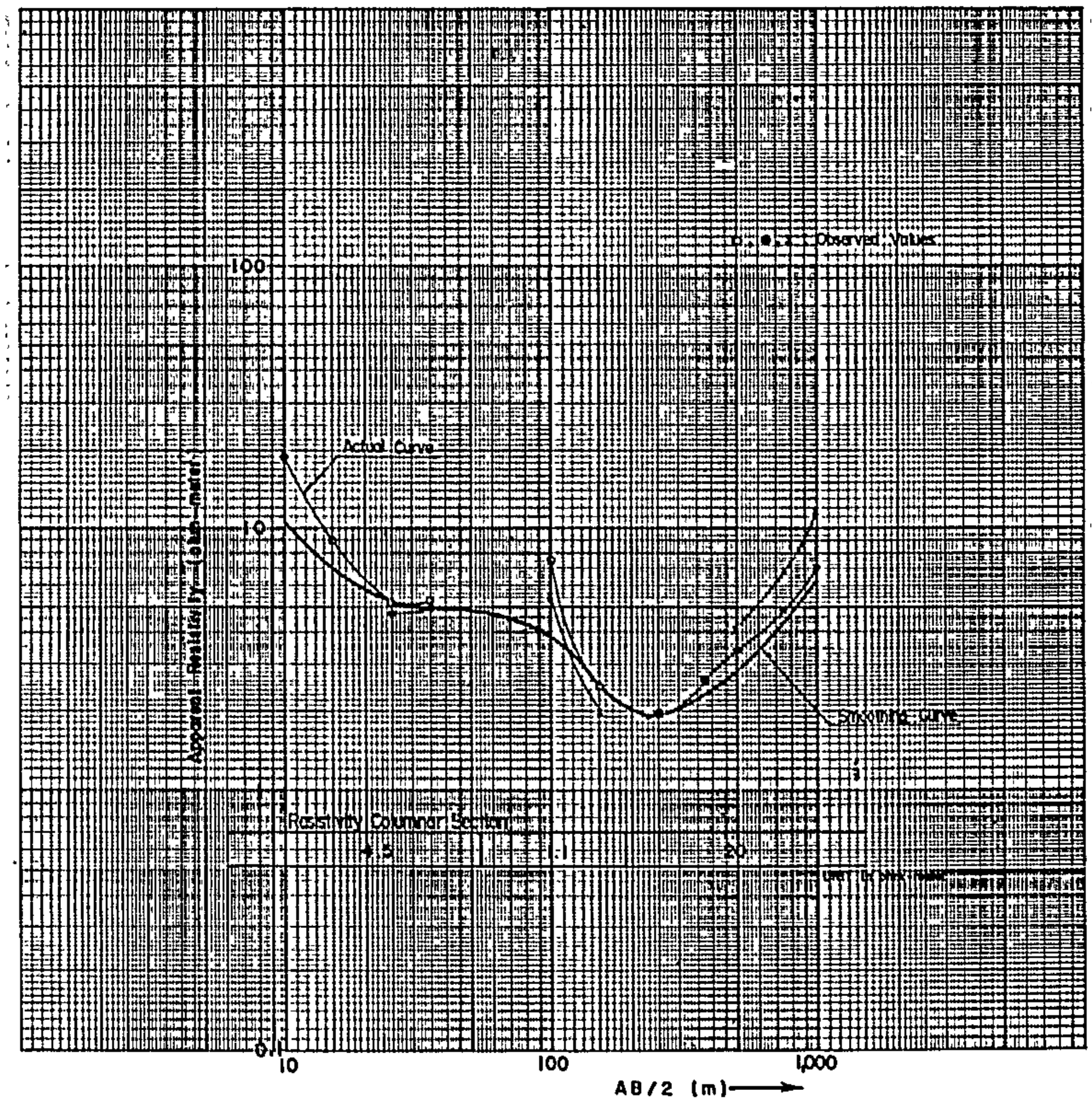
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE-2
Center Point No.71
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 ～ JAN. 1977

Fig.4-7-14



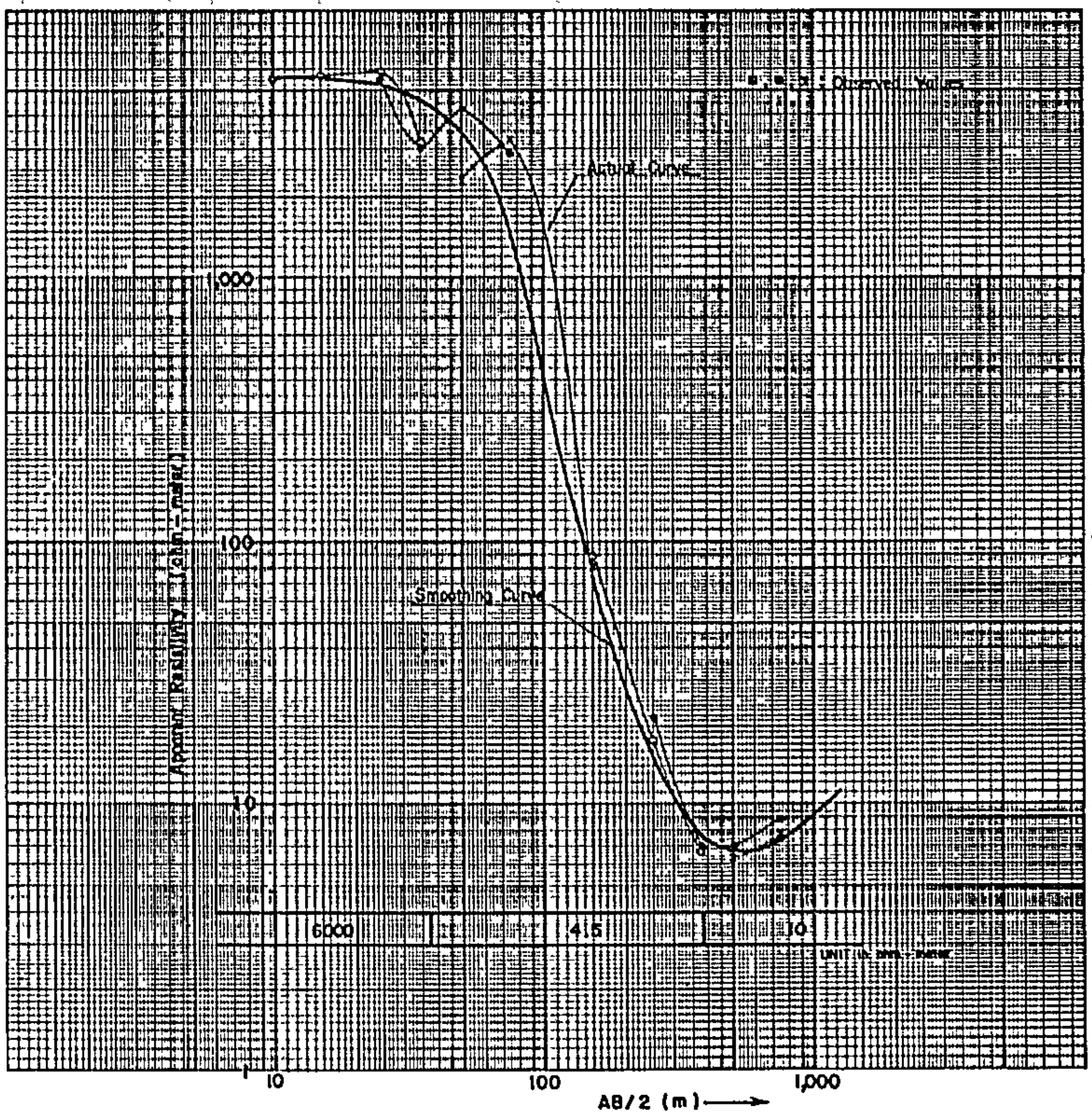
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE-2
Center Point No.81
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J.I.C.A.)

DEC. 1976 ~ JAN. 1977

Fig.4-7-15



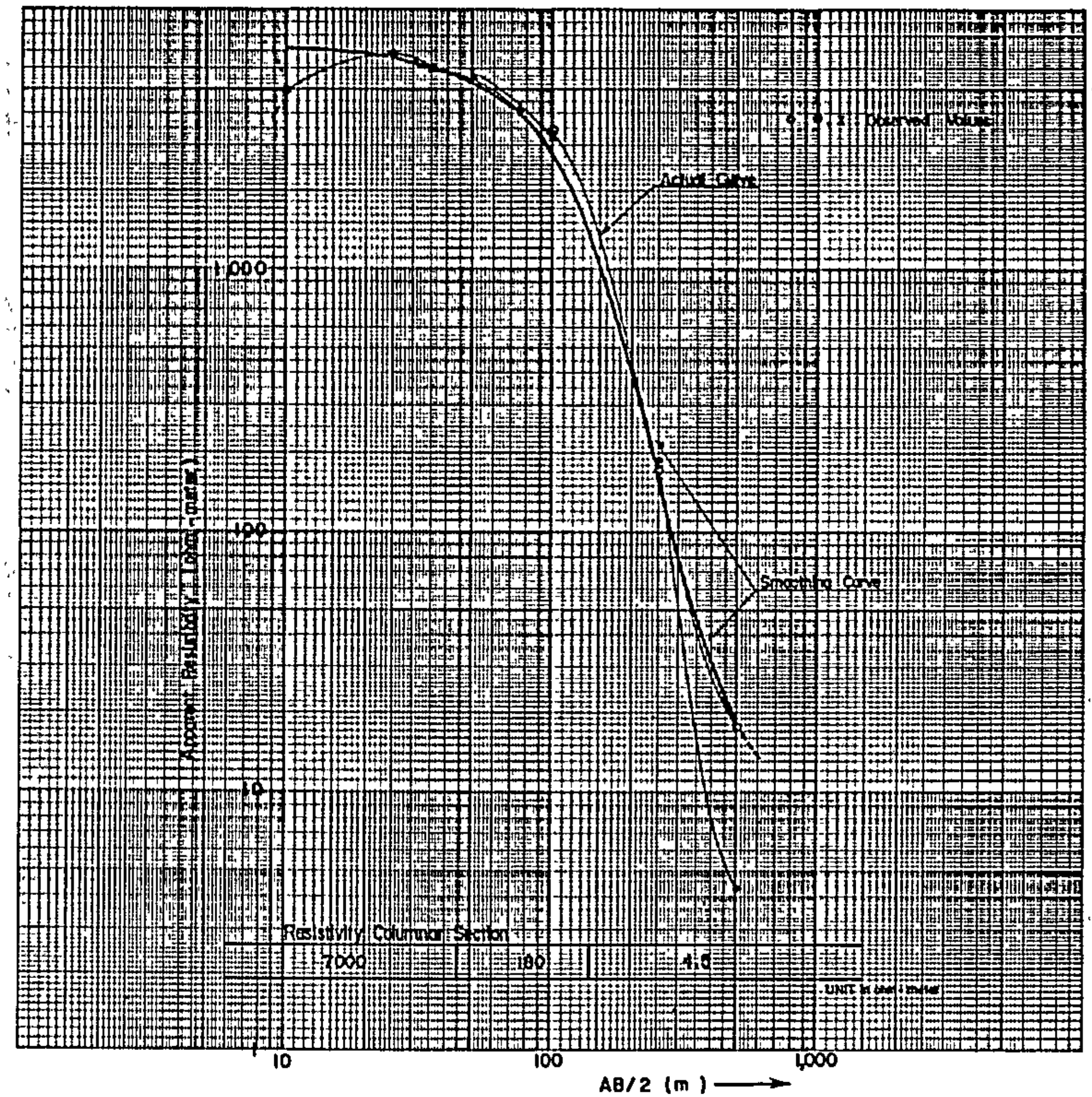
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE - 2
Center Point No. 90
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 — JAN. 1977

Fig. 4 - 7 - 16



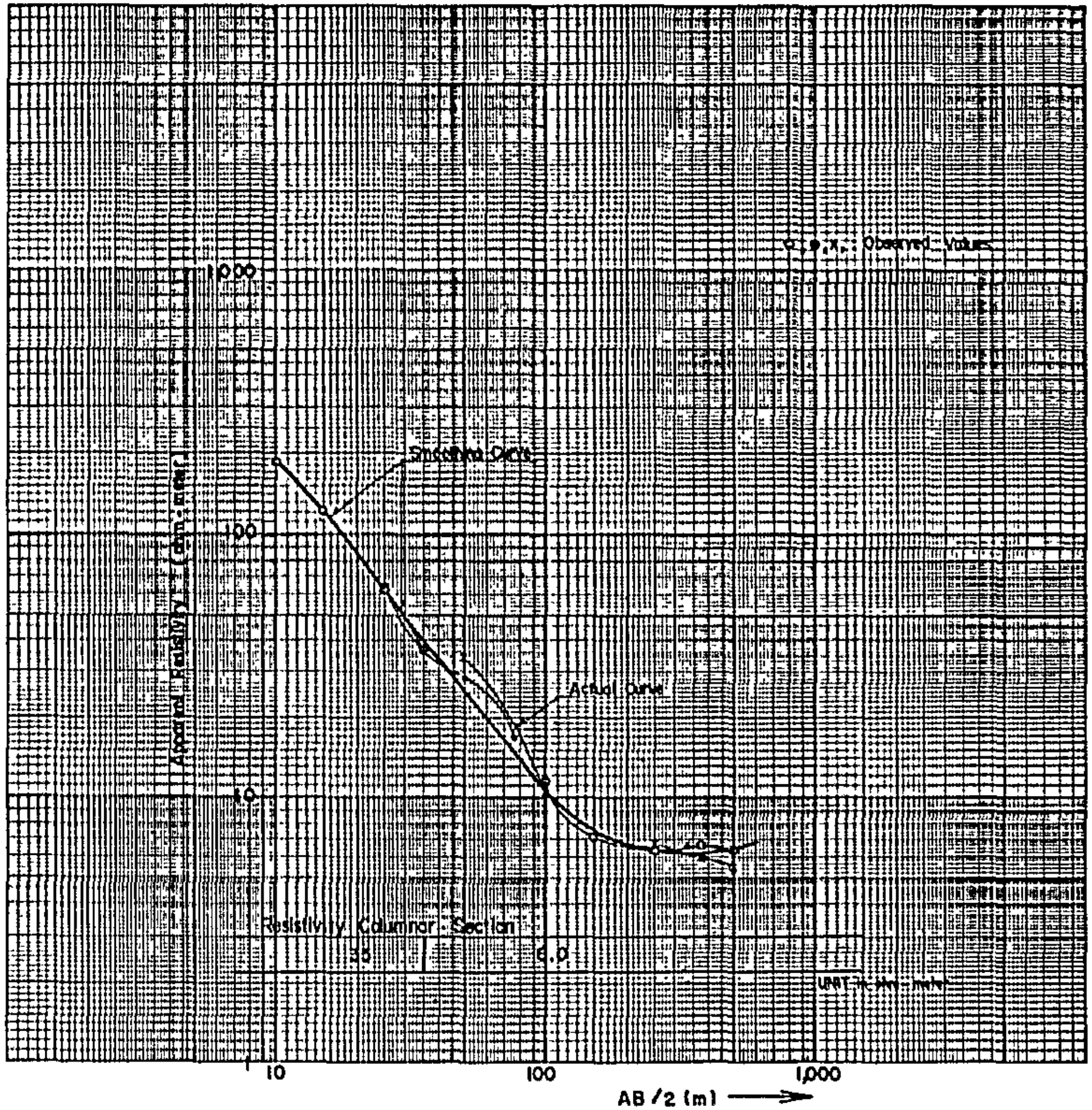
Geothermal Power Development Project
In Zunil,
the Republic of Guatemala

VES Curve of LINE-2
Center Point No.100
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 ~ JAN. 1977

Fig. 4-7-17



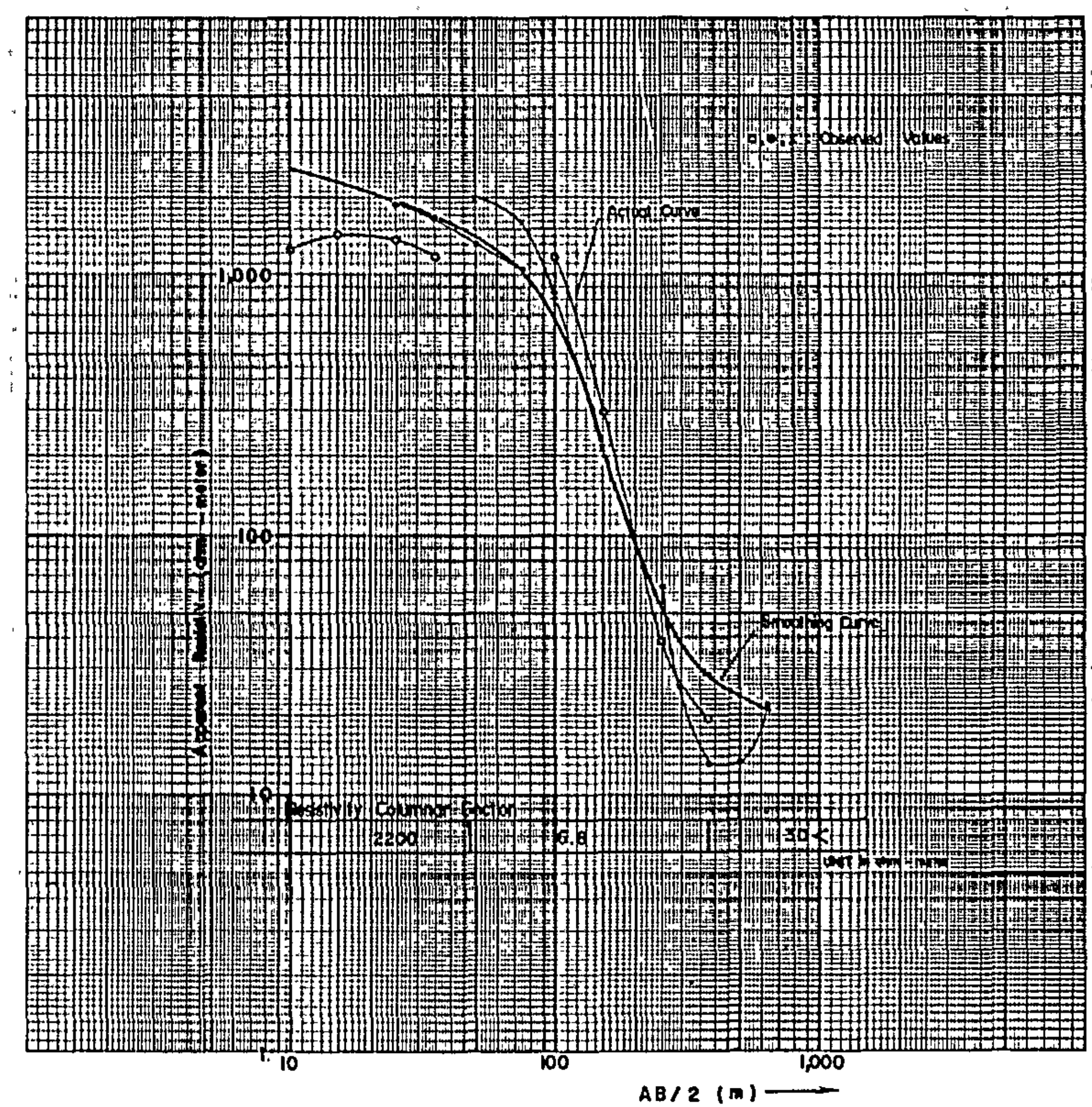
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE - 3
Center Point No. 21
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 ~ JAN. 1977

Fig.4-7-18

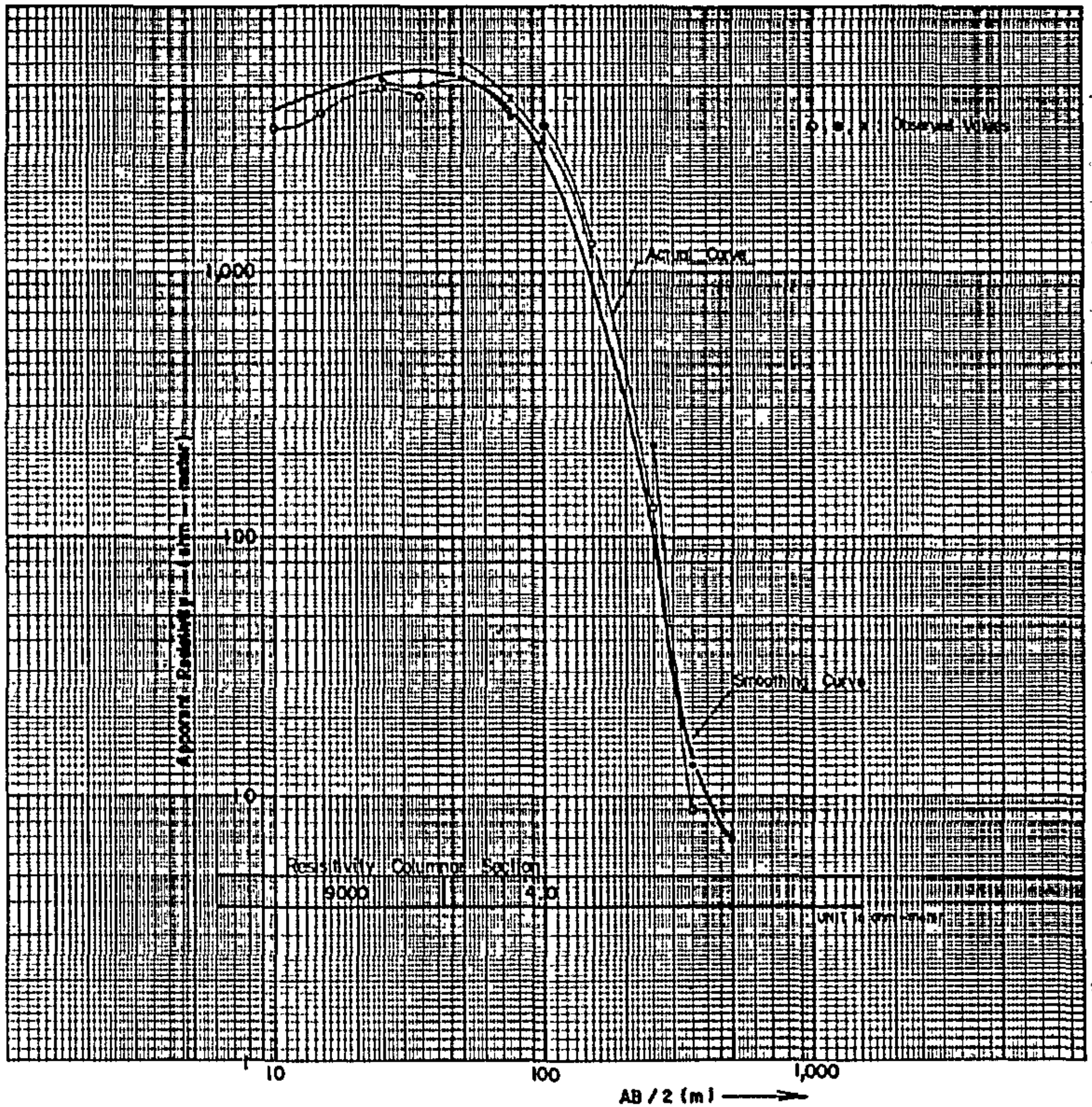


Geothermal Power Development Project
In Zunil,
the Republic of Guatemala

VES Curve of LINE - 3
Center Point No.31
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J.I.C.A.)
DEC. 1976 — JAN 1977

Fig 4-7-19



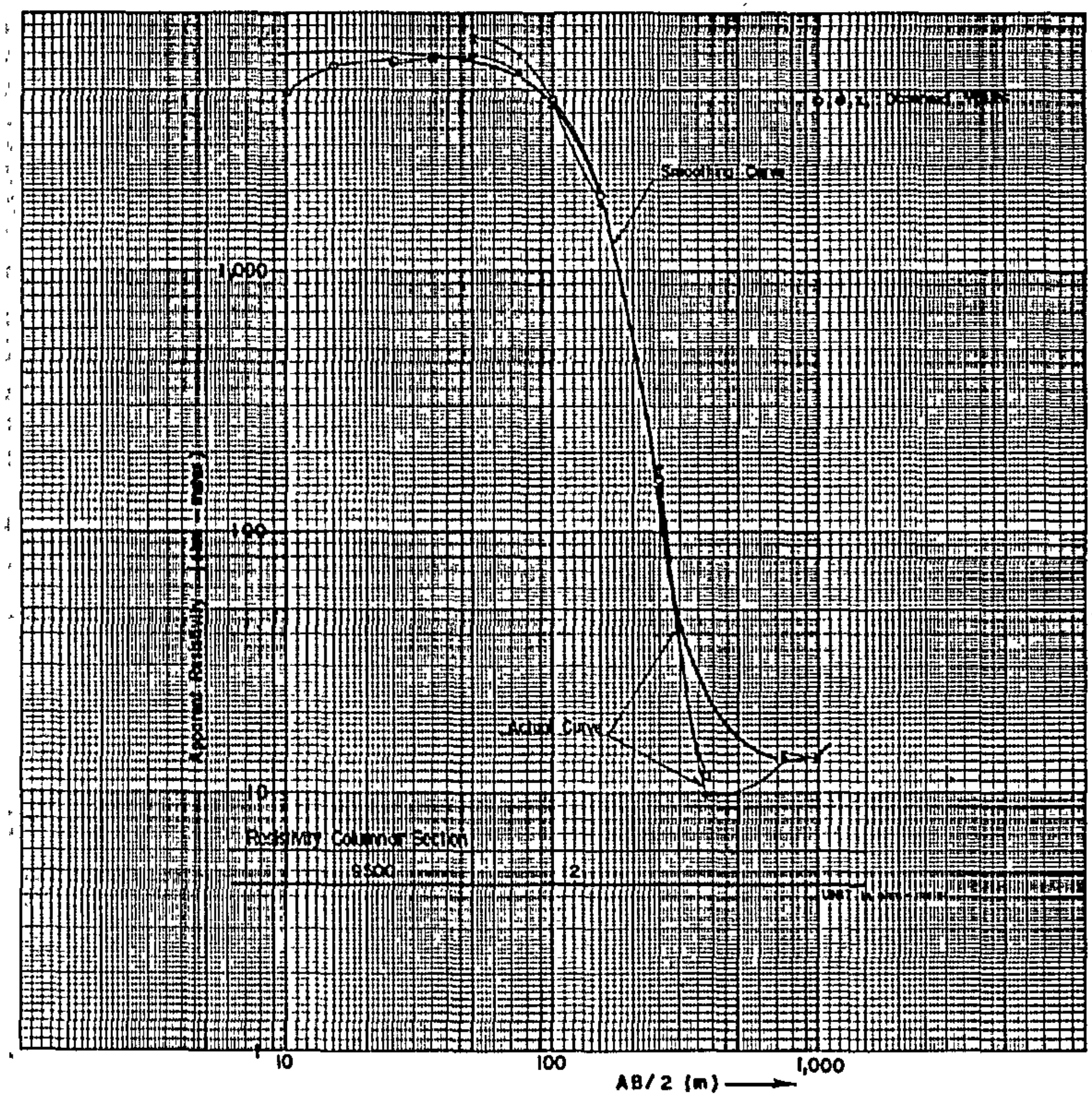
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE - 3
Center Point No. 41
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 — JAN. 1977

Fig.4-7-20



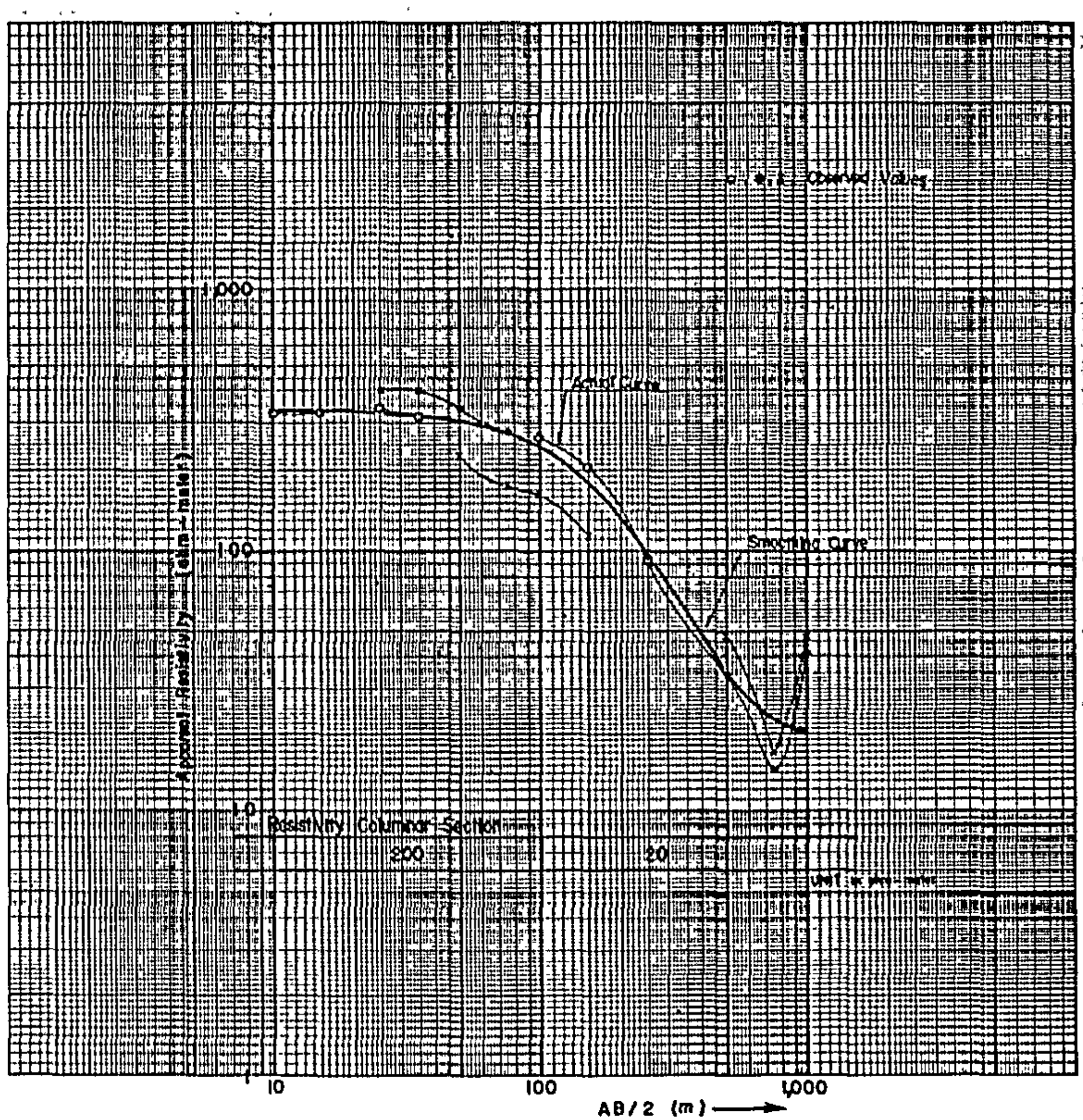
Geothermal Power Development Project
In Zunil,
the Republic of Guatemala

VES Curve of LINE−3
Center Point No.50
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPRATION AGENCY
(J.I.C.A.)

DEC. 1976 − JAN 1977

Fig.4-7-21



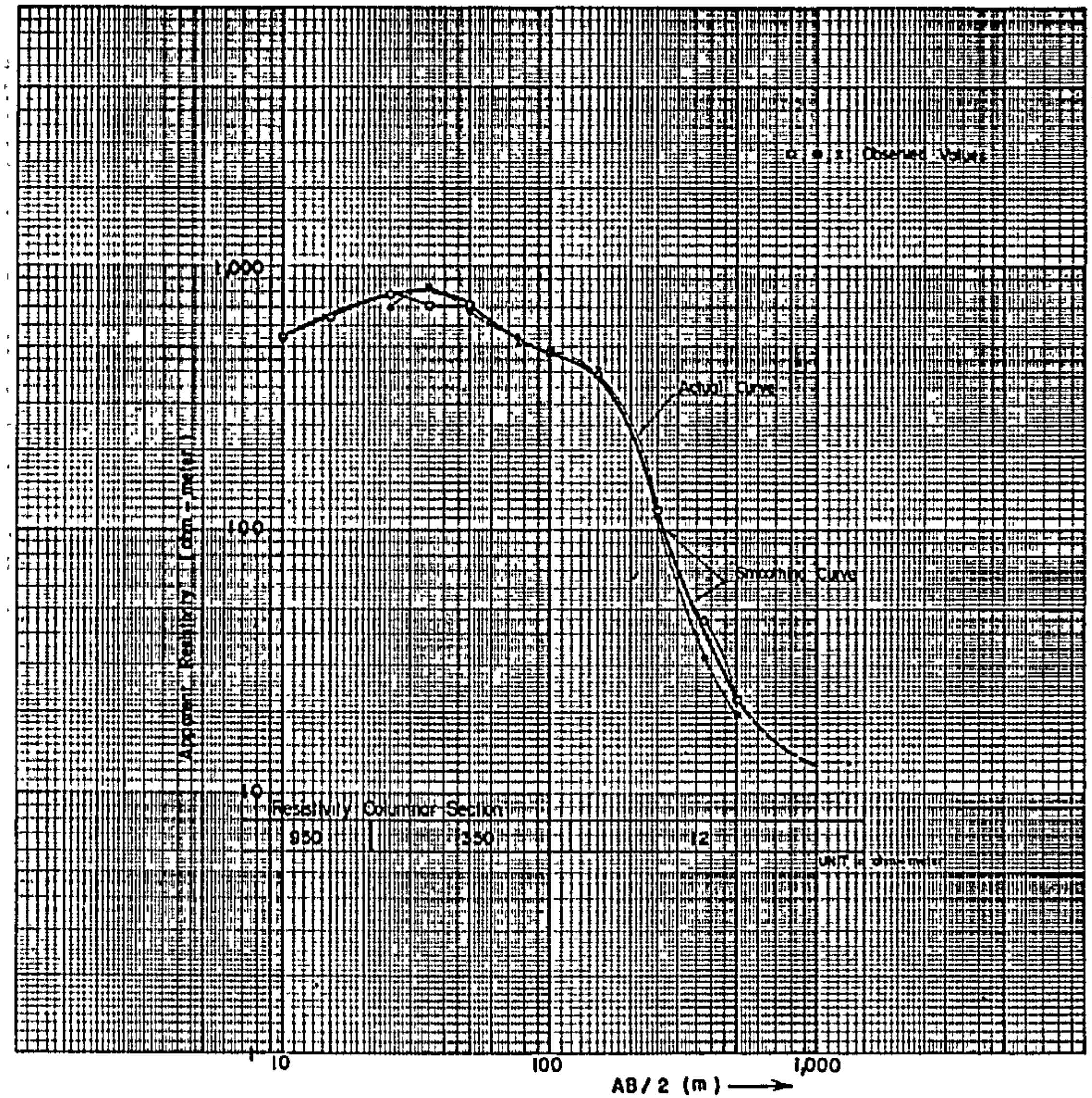
Geothermal Power Development Project
In Zunil,
the Republic of Guatemala

VES Curve of LINE - 3
Center Point No.81
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERTION AGENCY
(J. I. C. A.)

DEC. 1976 ~ JAN. 1977

Fig.4-7-22



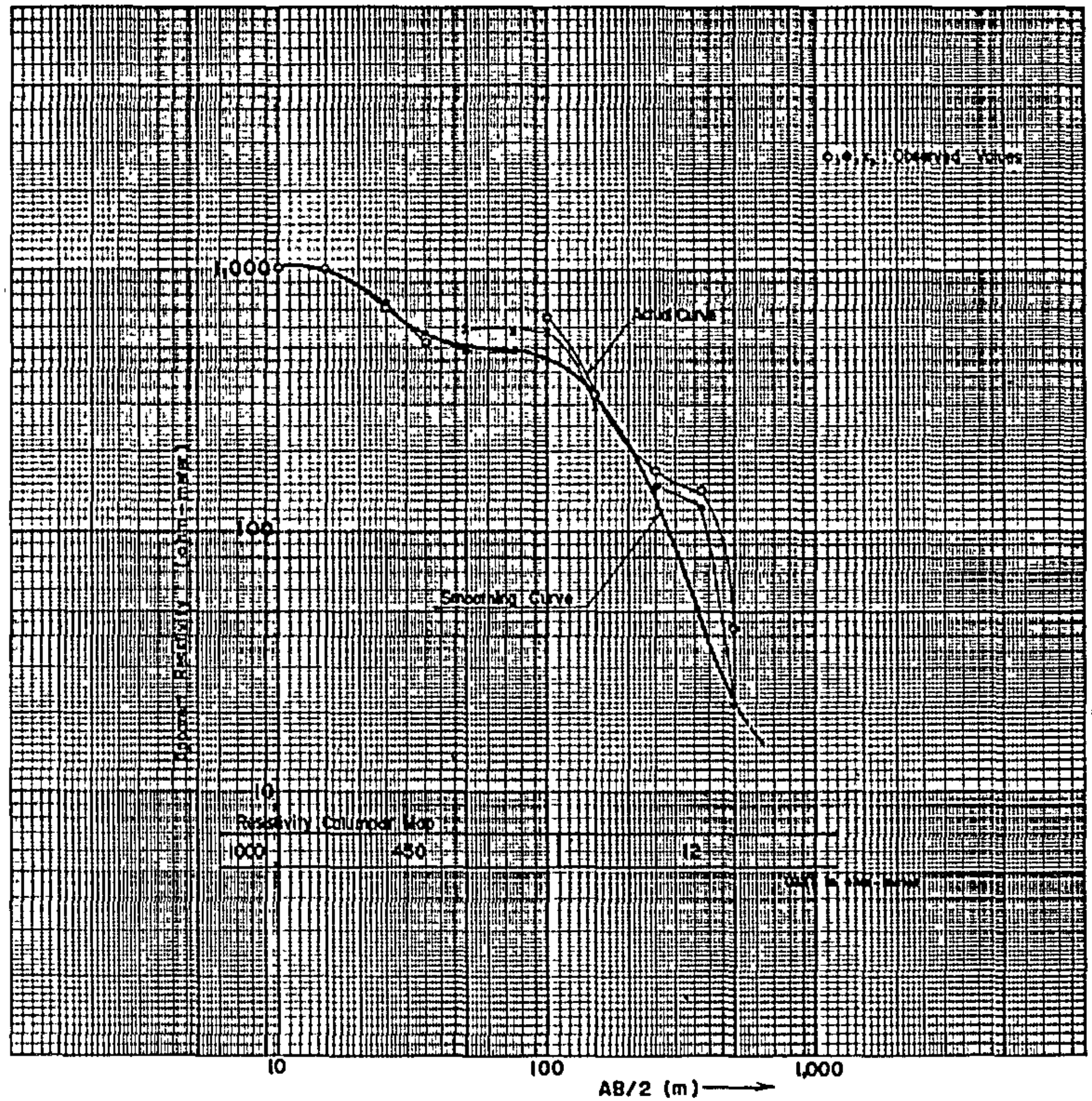
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE-3
Center Point No.91
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 — JAN 1977

Fig.4-7-23



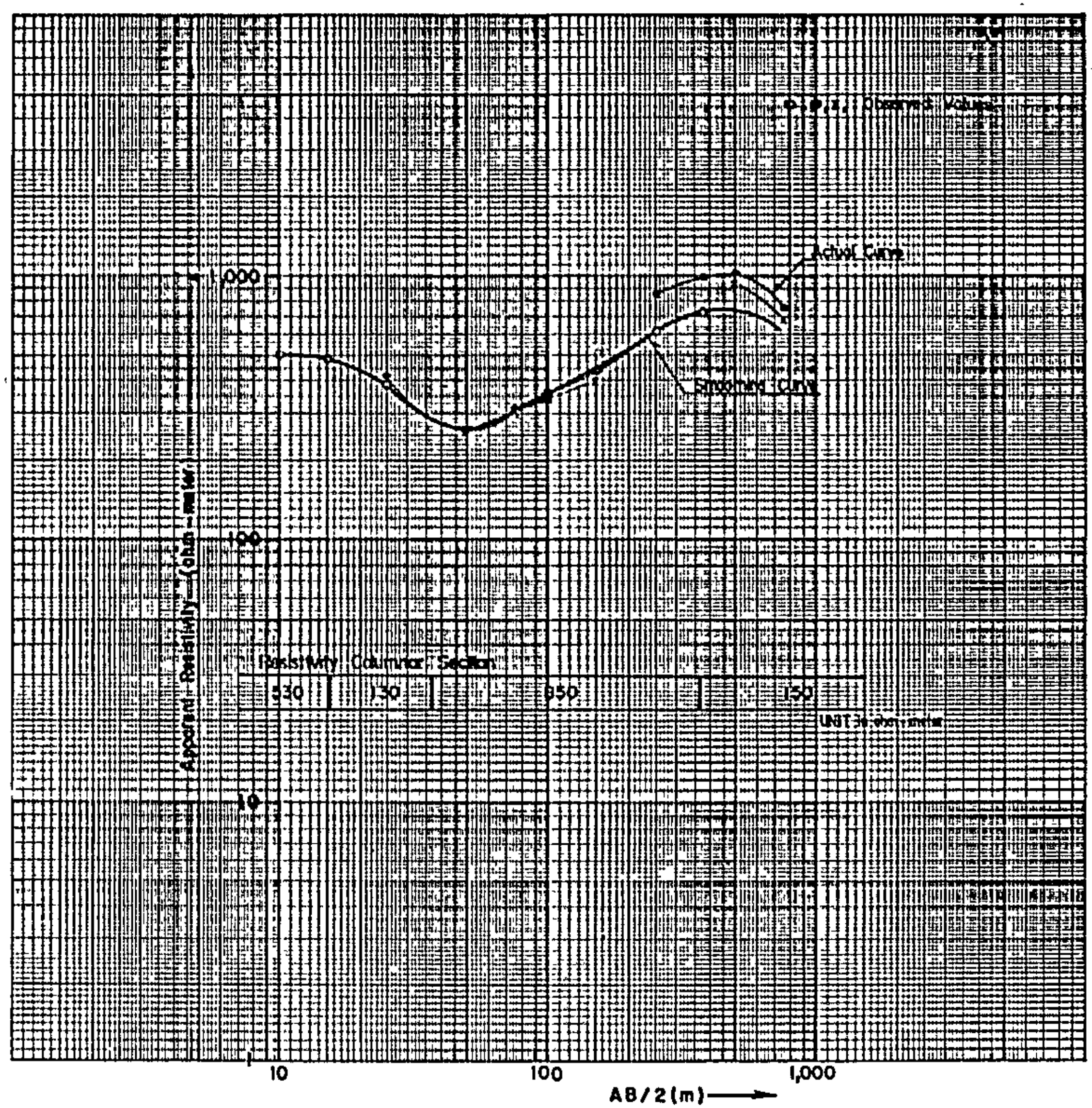
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE-3
Center Point No.101
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 ~ JAN. 1977

Fig.4-7-24



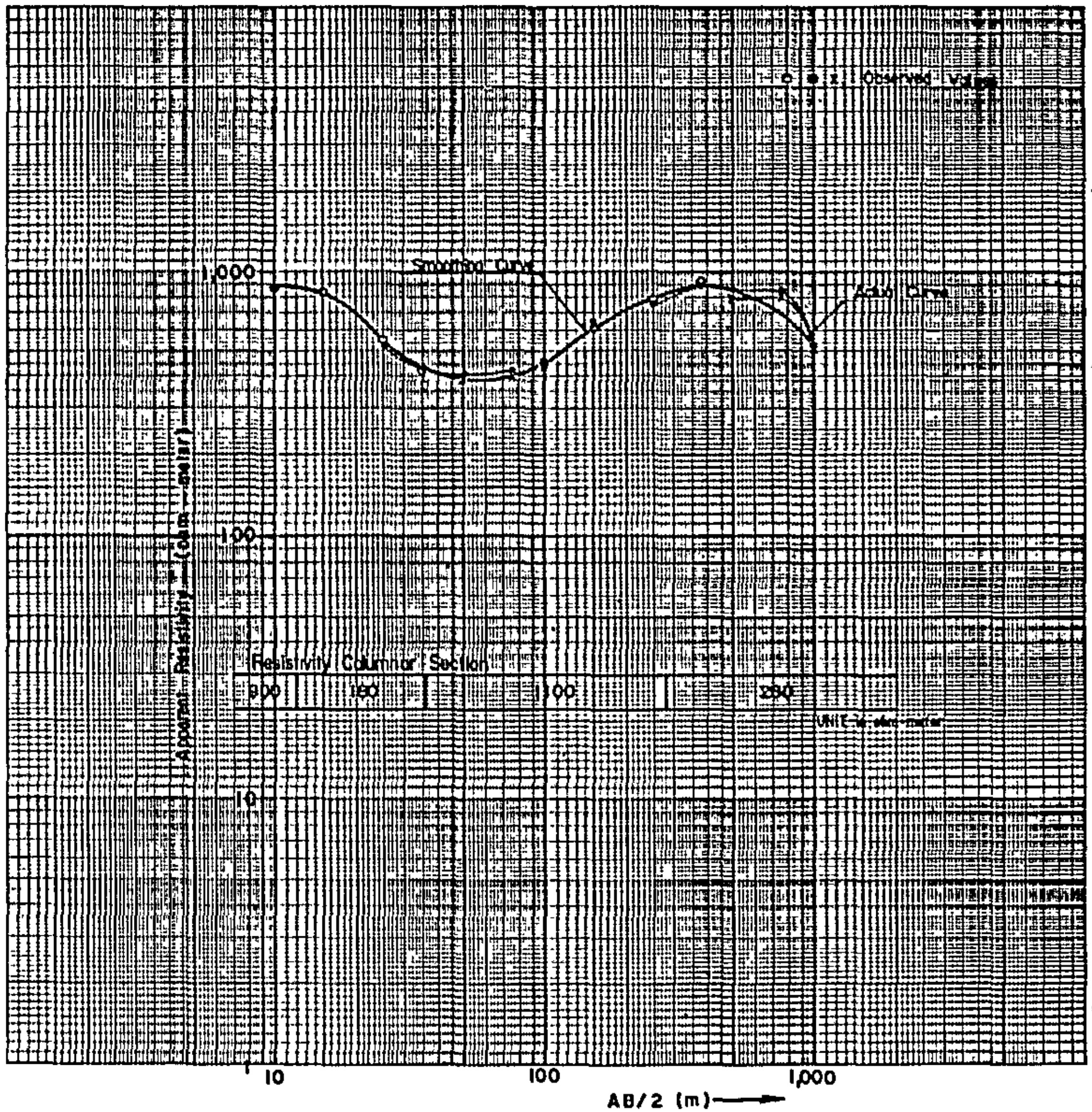
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE-4
Center Point No. 31
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J.I.C.A.)

DEC. 1976 — JAN 1977

Fig.4-7-25



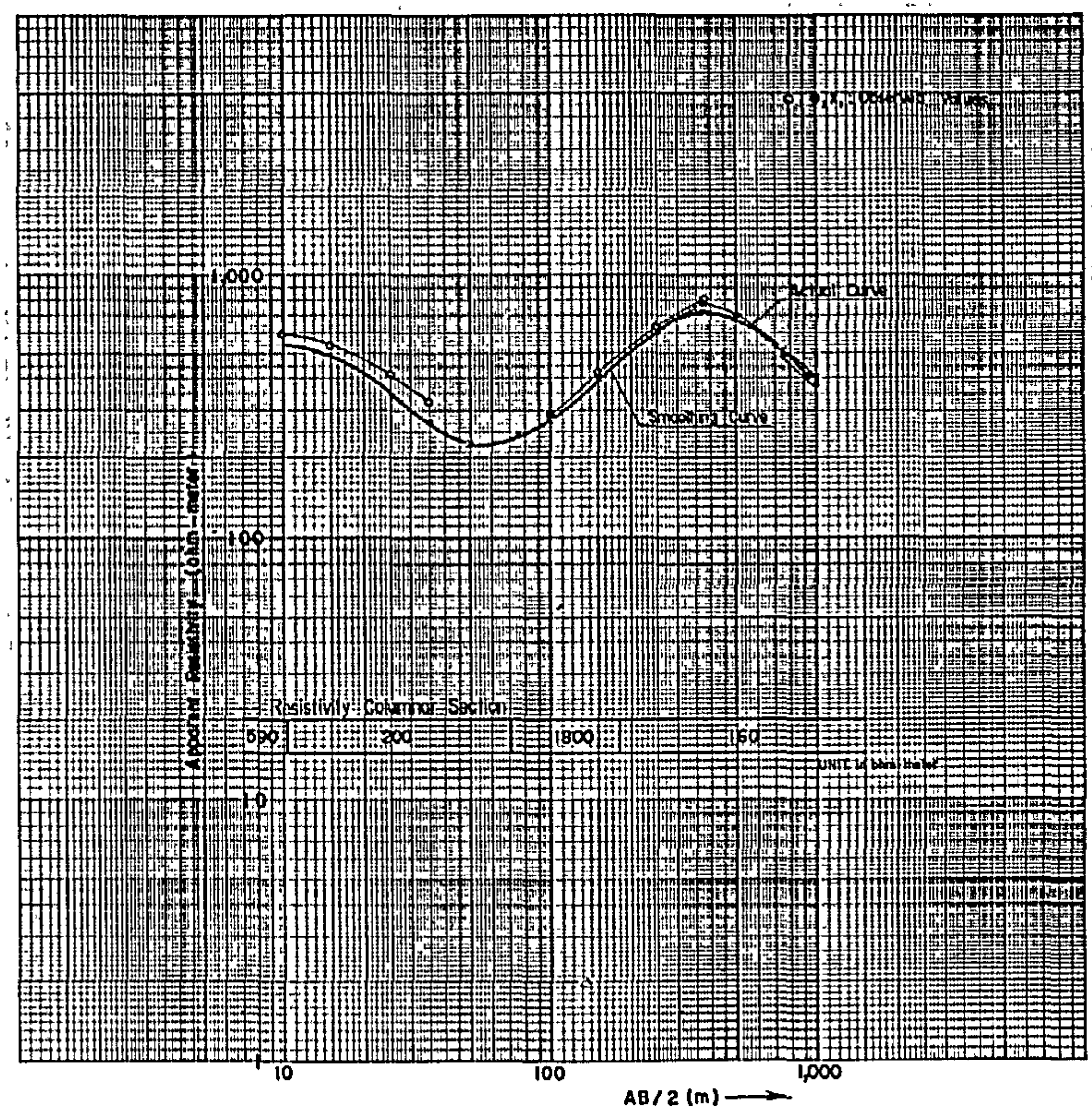
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE - 4
Center Point No. 41
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 ~ JAN. 1977

Fig.4-7-26



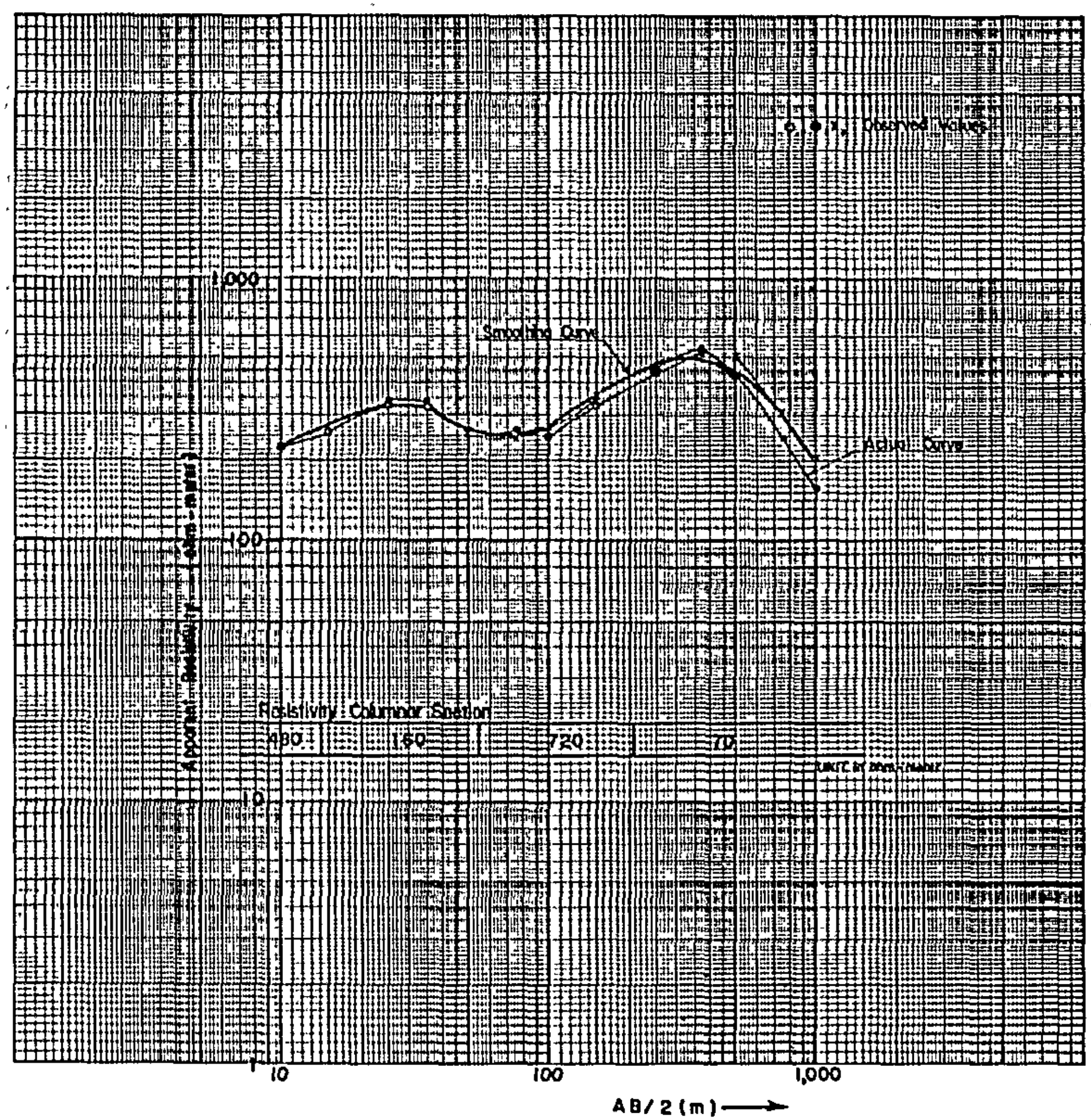
Geothermal Power Development Project
In Zunil,
the Republic of Guatemala

VES Curve of LINE - 4
Center Point No. 51
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 ~ JAN. 1977

Fig.4-7-27



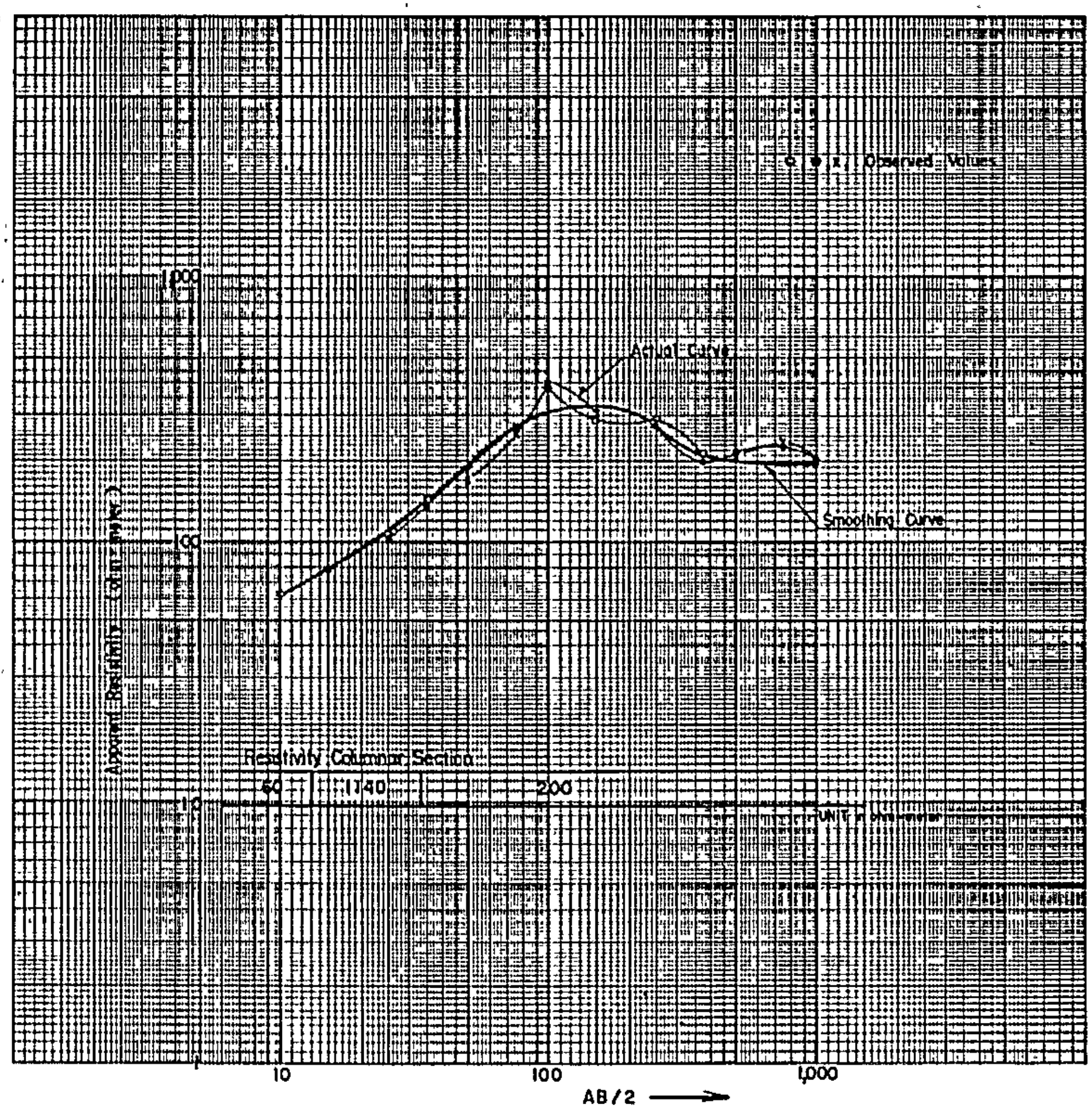
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE-4
Center Point No. 61
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J.I.C.A.)

DEC. 1976 JAN. 1977

Fig. 4-7-28



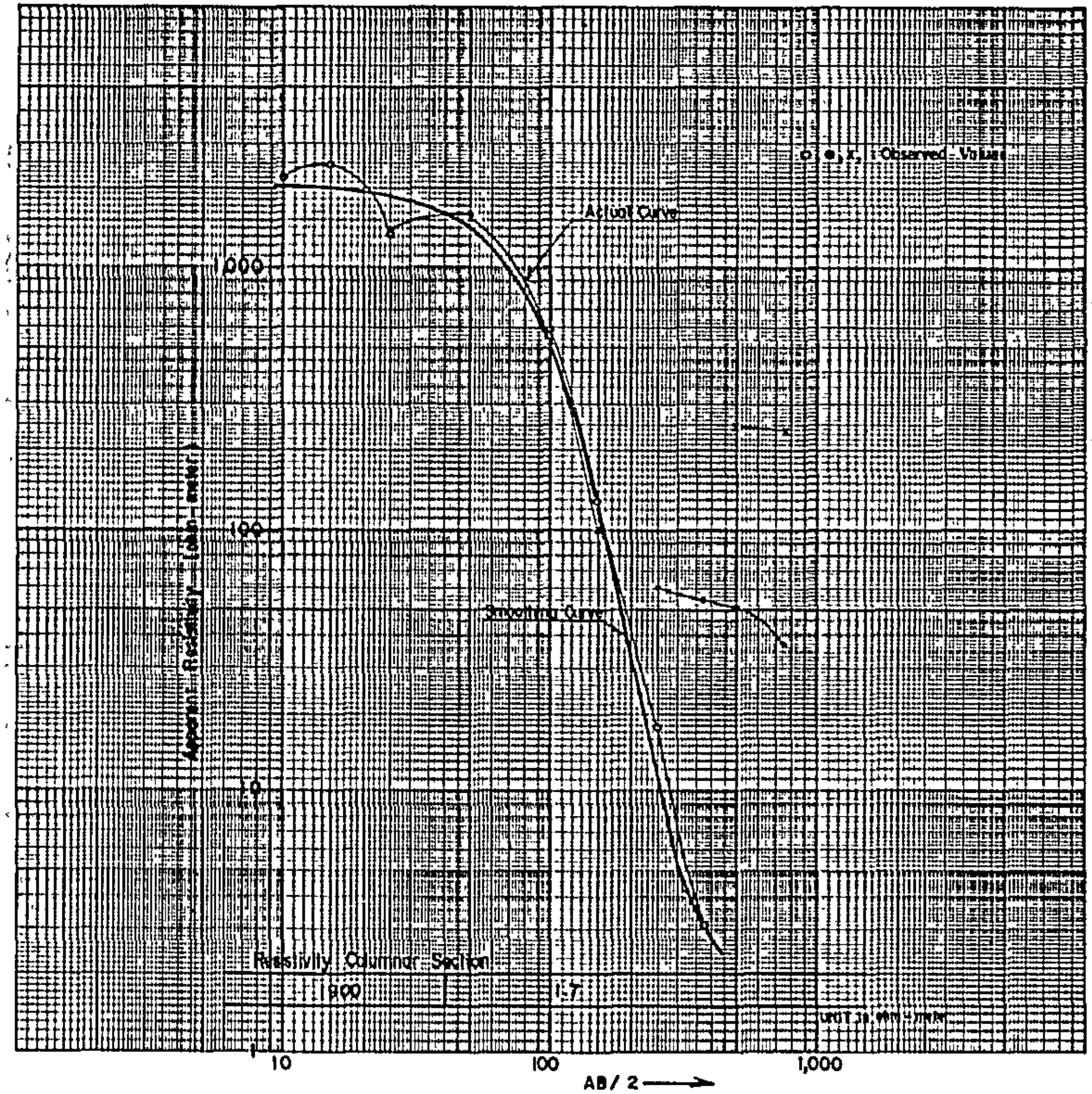
Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE - 4
Center Point No. 71
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A)

DEC. 1976 ~ JAN. 1977

Fig.4-7-29



Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

VES Curve of LINE - 4
Center Point No. 81
(Vertical Electrical Sounding Curve)

JAPAN INTERNATIONAL COOPERATION AGENCY
(J. I. C. A.)

DEC. 1976 — JAN. 1977

Fig. 4-7-30

According to the results of the electrical survey done in the geothermal fields where the geothermal power stations are located. in Japan as well as in the world, a layer (or a zone) with the resistivity (the apparent resistivity) lower than several Ω m has coincided with a layer (or an area) producing the geothermal fluid, so that it may be certain that such layer (or zone) has the high geothermal potential, with the geothermal fluid of high temperature.

Therefore, from the results of the electrical survey done in the geothermal fields, it is important to interpret the characteristics of a layer (or a zone) with the resistivity (or the apparent resistivity) lower than several Ω m.

(1) Line-1 (Fig. 4-8-1)

As a whole, the resistivity structure in Line-1 seems to consist of four resistivity layers. From the difference of the resistivity layers, the faults are assumed at two points. and one being between No. 63 and No. 71 of the central part of Line-1, and another being between No. 85 and No. 91 of the western part of Line-1. The former may correspond to the Fault F, which was pointed out by the geological survey.

The resistivity structure in the northern part of No. 63, may consist of four layers. The 1st layer has the resistivity of 4.000 to 10,000 Ω m and the thickness of about 100m, but it becomes thinner to the south and disappears at the fault between No. 63 and No. 71. It seems to correspond to Zunil Water Fall Lava and its weathered layer. The 2nd layer. having the resistivity of 320 to 420 Ω m and the constant thickness of about 100m. may correspond to Almolonga Lava. The 3rd layer having relatively low resistivity of 8 to 14 Ω m and the thickness of 400 to 500m. may correspond to Tertiary rock, which seems to be altered because of its relatively low resistivity. The 4th layer. having the resistivity higher than 90 Ω m at lowest. and the depth of 600 to 700m, may correspond to granodiorite, which is considered as the basement rock in this area.

The area between the above-mentioned two faults may also consist of four layers. The 1st layer having the resistivity of 120 to 250 Ω m and the thickness of 5 to 50m, increasing its thickness to the south, may correspond to alluvial deposits. The 2nd layer, having the resistivity of 35 to 50 Ω m and the thickness of 50 to 80m, decreases its thickness to the south, and disappears near No. 85. It may correspond to Almolonga Lava, but, because of its resistivity of one-tenth of the one in the northern part of No. 63, it may be altered or contain hot-spring water. The 3rd layer, having the low resistivity of several Ω m and the thickness of 200 to 300m, with decreasing thickness to the south, may contain the geothermal fluid of high temperature, because of such low resistivity. The 4th layer having the resistivity higher than 30 Ω m has the depth of about 400m near No. 71, and decreases its depth to the south, so that it is about 300m near No. 85. Because it has lower resistivity and shallower depth than the one in the northern part of No. 63, it may be the rocks different from granodiorite, which may be the basement rock in this survey area.

The southern part of Line-1 may consist of three layers. And it is difficult to find the 4th layer. The 1st layer, having the resistivity of 200 to 400 Ω m and the thickness of 30m. may correspond to Almolonga Lava. The 2nd layer, having the resistivity of 35 Ω m and the thickness of 160m. may correspond to the geothermal altered rock or rock involving hot-spring water of Almolonga Lava. The 3rd layer. having the resistivity of 6.5 Ω m and undetermined depth may correspond to Tertiary rock involving the geothermal fluid of high temperature similar to the 3rd layer between the above-mentioned two faults.

From the entire area covered by Line-1, the relatively low resistivity layer lower than 20 Ω m was confirmed. If a high potential geothermal area is to be selected, the southern area of No.63 near the center of Line-1 corresponding to the area involving the geothermal fluid of high temperature, where the resistivity is several Ω m, will be chosen.

(2) Line-2 (Fig. 4-8-2)

One fault each is assumed between No.41 and No.51 of the eastern part of the Line-2, between No.71 and No.81 near the Samala River, and between No.81 and No.91 the west side of the Samala River making three faults in total from the resistivity structural layer.

In the eastern part of No.41, the resistivity structure may consist of three layers. The 1st layer has the resistivity of 300 to 400 Ω m and the thickness of 10 to 30m. The 2nd layer having the resistivity of 170 Ω m and the thickness of 60m near No.41, and decreases its thickness to the east, and disappears near No.31. The 1st and 2nd layers may correspond to Zunil Formation. The 3rd layer having the resistivity of 16 Ω m with undetermined thickness may correspond to the Quarternary lavas and/or Tertiary rocks, but, because of its relatively low resistivity, it may be altered or involve underground water.

In the area between No.51 and No.71, of the central part of the line, the resistivity structure may consist of four layers, but near No.71, the 2nd layer was not found. The 1st layer having the resistivity of 130 Ω m and the thickness of 5 to 20m near No.51 and No.61, but 50 Ω m and 70m near No.71, which may correspond to the superficial layer and the weathered layer of Old Volcan de Zunil Lava. The 2nd layer, which is not found at No.71, has the resistivity of 740 to 1,170 Ω m with the thickness of about 50m. It may correspond to rhyolite lave (Old Volcan de Zunil Lava). The 3rd layer has the resistivity of several Ωm and the thickness of 400 to 500m. It may contain geothermal fluid of high temperature. The 4th layer has the resistivity higher than 20 Ω m and the depth of about 550m. It may correspond to granodiorite which is considered as the basement rock in this area.

In the western part of No. 71 the resistivity structure may consist of four layers. But the 1st and 2nd layer are not found at No.81 near the Samala River so that a layer having the resistivity of 6,000 to 10,000 Ω m appears at two points of No.91 and No.100. Its thickness is 50m at No.100, and decreases to the south so that it disappears between No.81 and No.91. It may correspond to Zunil Water-Fall Lava. The 2nd layer having the resistivity of 180 Ω m and the thickness of about 100m are found at No.100, and may correspond to Almolonga Lava. The 3rd layer has the resistivity of 4.5 Ω m, and partially 1.1 Ω m at No.81. It thickness is about 200m near No.81 and about 400 m on the west side of the Samala River. It may contain geothermal fluid of high temperature. The 4th layer has the resistivity higher than 20 Ω m, and its depth is about 200m near No.81, and about 400m near No.91, and may increase to the west. There is a great possibility that the formation greatly differ from the one on the east side of the Samala River.

On Line-2, the resistivity of the 1st and 2nd layers differs, but layers deeper than the 3rd layer have similar characteristics. The shallower part near the ground surface consists of Zunil

Formation, Old Volcan de Zunil Lava and those weathered layers in the east side of the Samala River, and the Zunil Water Fall Lava and Almolonga Lava in the west side. Since the third layer has resistivity lower than several Ω m in the western area of No.51, except for 16 Ω m in the eastern area of No.41, it seems that the former area corresponds to the high geothermal potential area. The 4th layer is divided by the above-mentioned faults. In the eastern part of No.41, it was impossible to confirm because the area was beyond the east end of Line-2, but it seems that it has the depth shallower than 1,000m at deepest. Although the 4th layer seems to correspond to granodiorite, its uplifted layer near the Samala River seems to be different from granodiorite.

(3) Line-3 (Fig. 4-8-3)

Two faults are assumed, one between No.21 and No.31, on the west side of the line, and the other, near the Samala River in the central part of the line. The former seems to be extention of the fault between No.63 and No.71 on Line-1 and coincide with the Fault F discovered by the geological survey. Although the fault near the Samala River is estimated from the differences of the resistivity structure between the west and the east sides of the Samala River, it is difficult to determine its location, due to lack of center point near the Samala River.

The resistivity structures on the west and the east side are as follows:

On the west side of the Samala River, the resistivity structure seems to consist of about three layers, and the resistivity and the thickness of the shallower part is different on both of the Fault F. On the east side of the Fault F, the 1st layer has the resistivity of 2,200 to 9,500 Ω m, and the constant thickness of about 50m. On the other hand, on the west side, it has the resistivity of 35 Ω m. These formations may correspond to Zunil Water Fall Lava and alluvial deposits, respectively. The 2nd layer has the resistivity of 12 Ω m on the east side and 6 Ω m on the west. It seems to correspond to the Tertiary rocks, and, especially, in the west side, there seems to be a geothermal fluid of high temperature. The 3rd layer, was not confirmed on the west side, as the line was at its end, but on east side it has the resistivity higher than 30 Ω m and seems to correspond to granodiorite, but its thickness is not determined.

On the east side of the Samala River, the resistivity structure seems to consist of three layers. The 1st layer has the resistivity of 950 to 1,300 Ω m and the thickness of 10 to 15m, but it does not appear at No.81. The 2nd layer has the resistivity of 200 to 450 Ω m and the thickness of 100m. The 3rd layer has the resistivity of 12 to 20 Ω m. It seems that the 1st, 2nd and 3rd layers correspond to the Quarternary lava and its weathered layer (Zunil Formation), and Old Volcan de Zunil Lava at the unknown Tertiary rocks, respectively. A layer having the resistivity higher than 30 Ω m on the west side of the Samala River does not appear on the east side.

(4) Line-4 (Fig. 4-8-4)

On Line-4, the resistivity structure seems to consist of four layers, except near No.81. The existence of the fault was assumed between No.71 and No.81. The resistivity structures in both side of the above-mentioned fault are as follows:

On the east side of the above-mentioned fault, the 1st layer has the resistivity of 480 to 1,000 Ω m with a thickness of 10 to 20m, and does not appear between No.61 and No.71. The 2nd layer has the resistivity of 60 to 200 Ω m with a thickness of 30m, and disappears near No.81. The 1st and 2nd layers seem to correspond to Zunil Formation and its weathered layer. The 3rd layer has the resistivity of 720 to 1,140 Ω m with a thickness of about 350m, but decreases its thickness to the west to about 30m near No.71. It seems to correspond to Old Volcan de Zunil Lava. The 4th layer having the resistivity of 70 to 280 Ω m seems to correspond to granodiorite or the unknown Tertiary rocks.

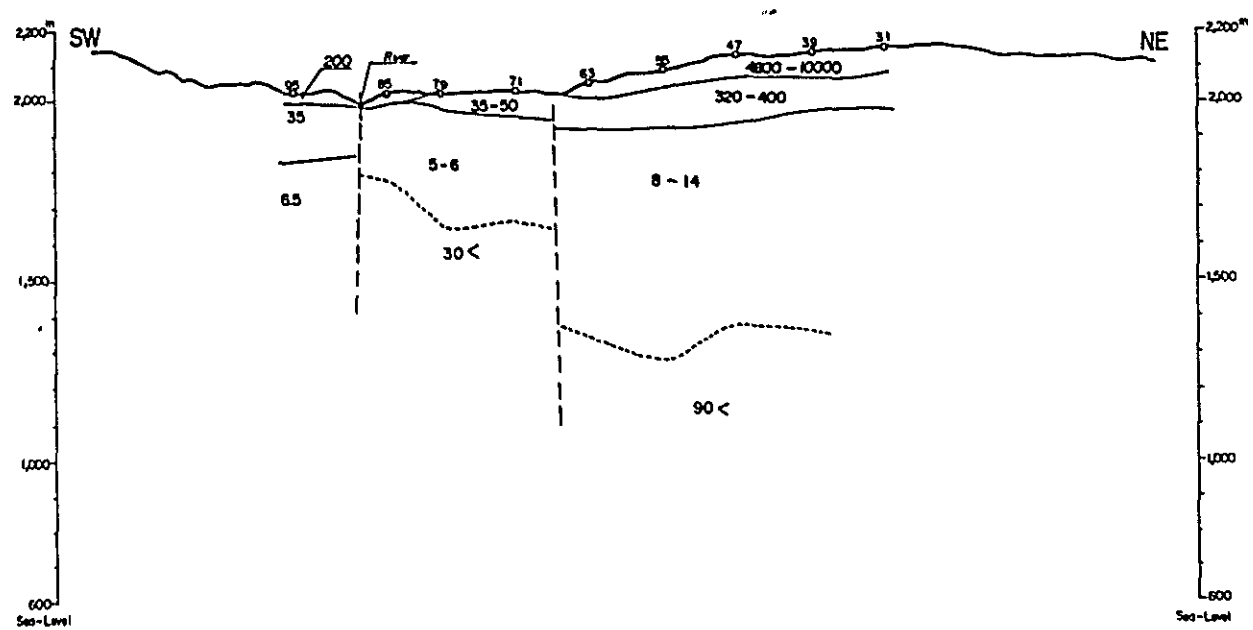
On the west side of the above-mentioned fault, the 1st layer having the resistivity of 1,900 Ω m and the thickness of 50m, seems to correspond to Old Volcan de Zunil Lava. The 2nd layer has the resistivity of 1,700 Ω m with unknown thickness, and seems to contain geothermal fluid of high temperature.

4-5-5 Resistivity Blockdiagram

The resistivity blockdiagram is made in order to make a better interpretation for the distribution of resistivity layers on each sections, by means of presenting three-dimentional underground structure sections of each lines (Fig. 4-9).

The layers, having the relatively low resistivity that is lower than 20 Ω m, are distributed in the whole area except in the southeast of this survey area, but there is a great possibility that it extends further to the southwest, as well as to the north of this survey area.

Especially, three areas having high geothermal potential exists, which are located in the western area of No.51 on Line-2, in



Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

RESISTIVITY SECTION

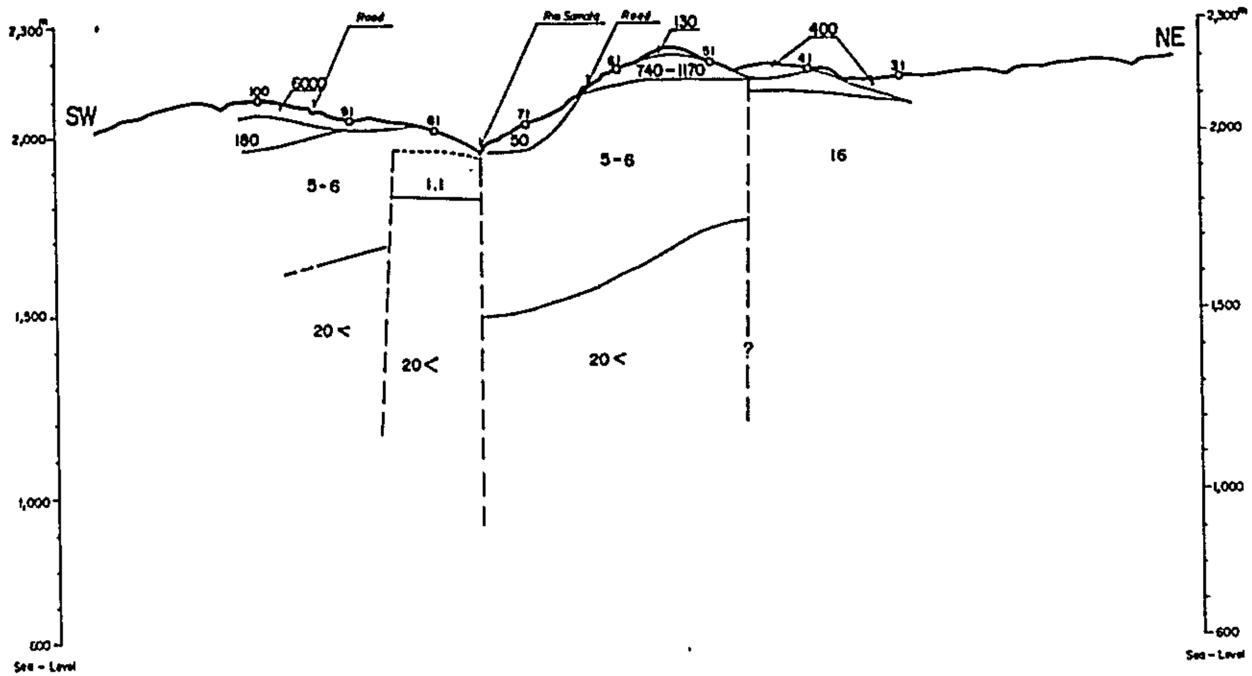
LINE - I

- - - - Contrast Line of Resistivity Layer
—— Fault
—o— Center Point and Line

UNIT IN OHM - METER
DEC 1976 to JAN 1977

Fig 4-8-1

JAPAN INTERNATIONAL COOPERATION AGENCY
TOKYO , JAPAN



Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

RESISTIVITY SECTION

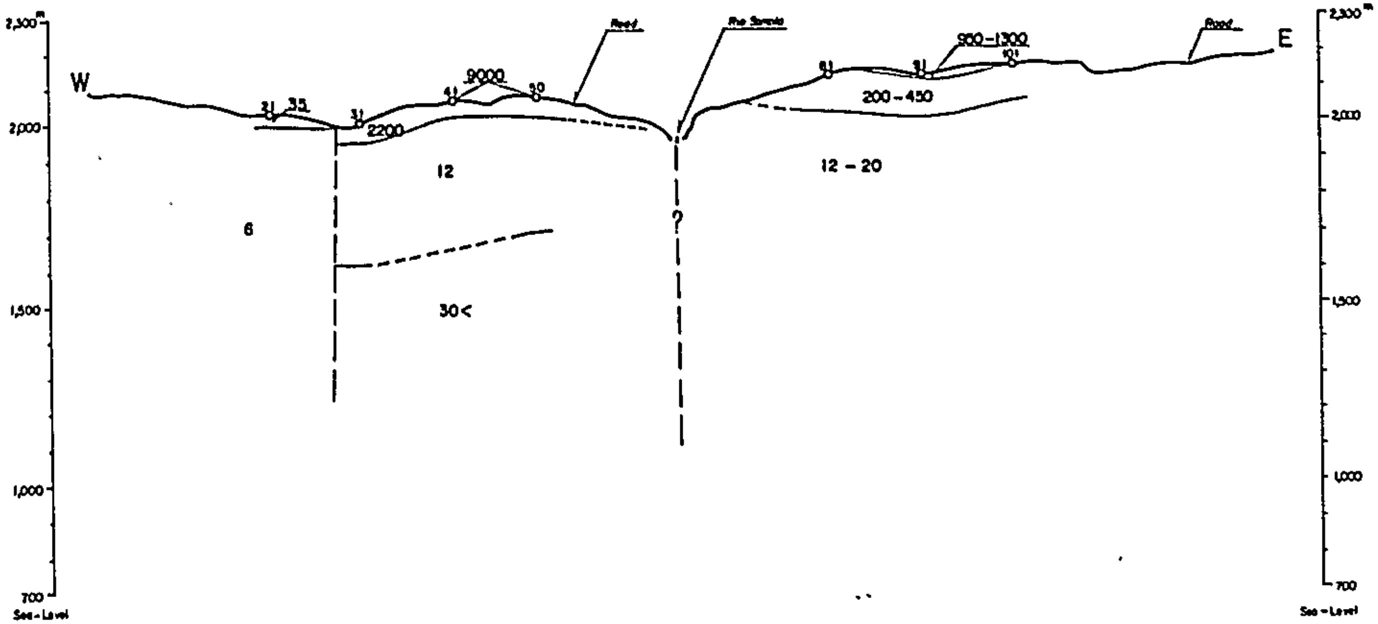
LINE - 2

Contrast Line of Resistivity Layer
Fault
Center Point and Line

UNIT IN OHM-METER
DEC. 1976 to JAN 1977

Fig. 4-8-2

JAPAN INTERNATIONAL COOPERATION AGENCY
TOKYO, JAPAN



Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

RESISTIVITY SECTION

LINE - 3

Contrast Line of Resistivity Layer

Fault

Center Point and Line

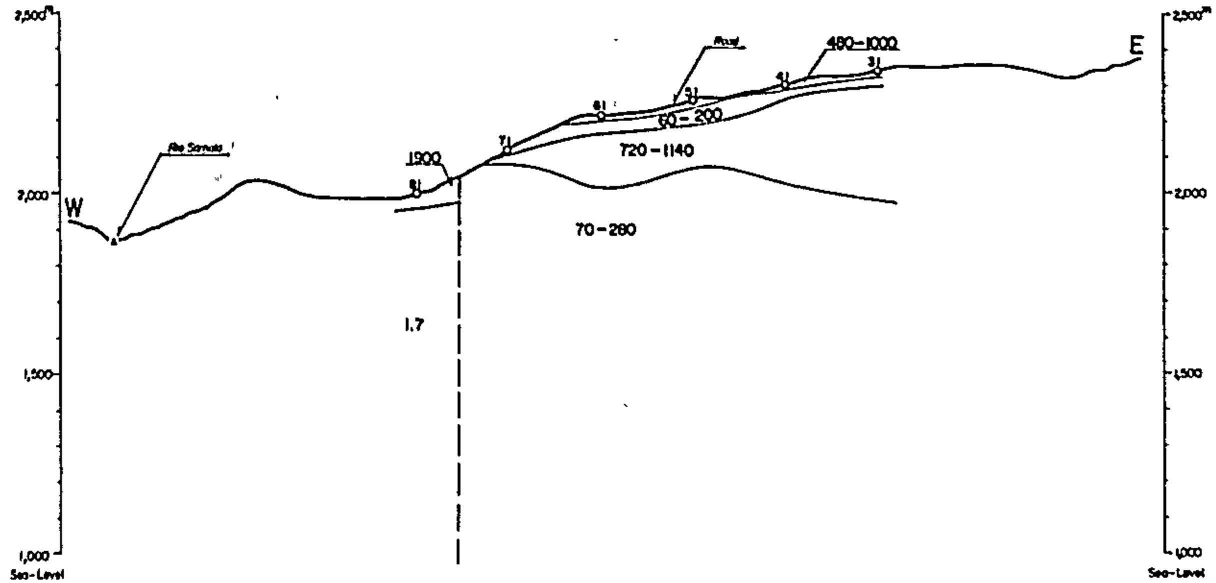
UNIT IN OHM-METER

DEC. 1976 to JAN. 1977

Fig. 4-8-3

JAPAN INTERNATIONAL COOPERATION AGENCY

TOKYO, JAPAN



Geothermal Power Development Project
In Zunil,
the Republic of Guatemala

RESISTIVITY SECTON

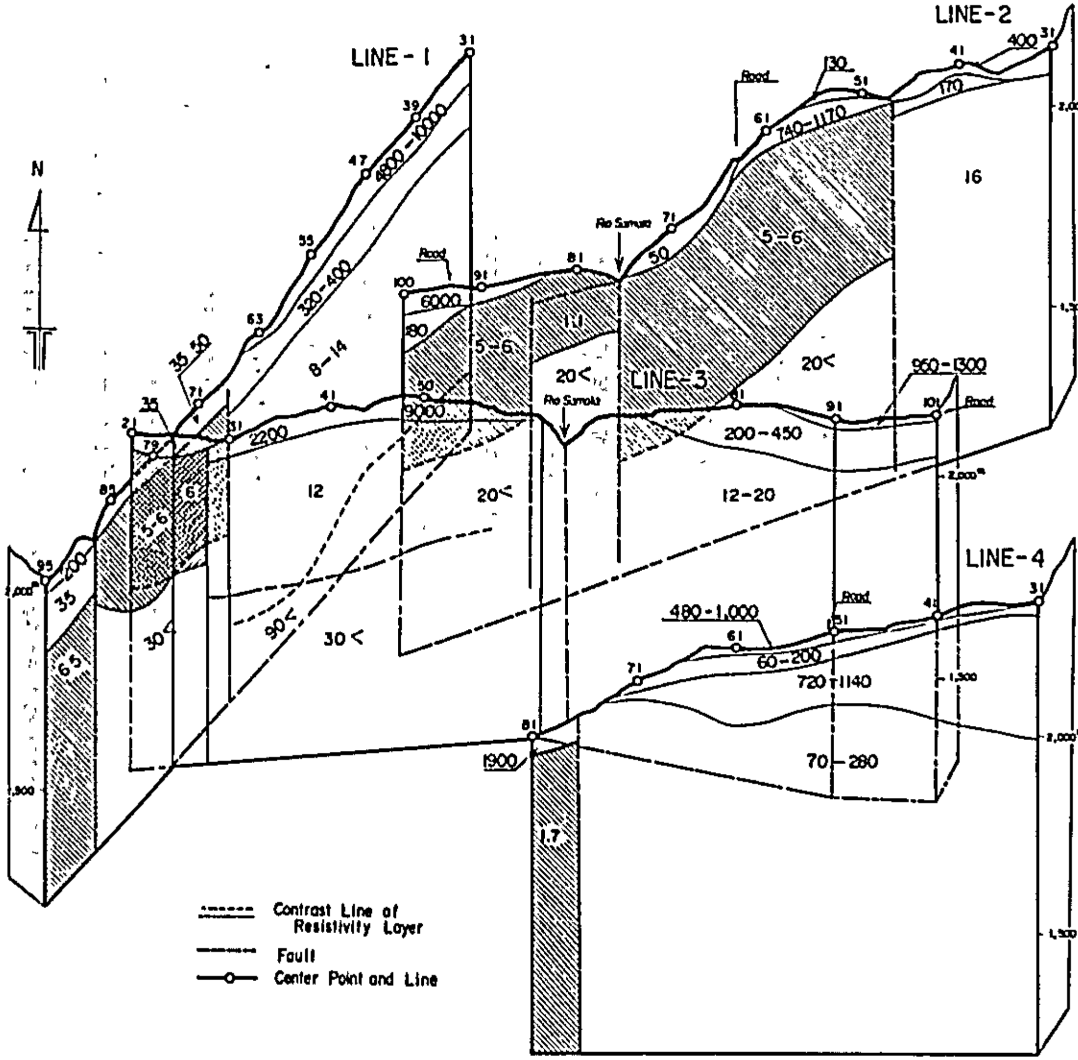
LINE - 4

Contrast Line of Resistivity Layer
Fault
Center Point and Line

UNIT IN OHM-METER
DEC. 1976 to JAN. 1977

Fig. 4-8-4

JAPAN INTERNATIONAL COOPERATION AGENCY
TOKYO, JAPAN



Geothermal Power Development Project
in Zunil,
the Republic of Guatemala

RESISTIVTY BLOCK DIAGRAM

0 800m

UNIT IN OHM-METER

JAPAN INTERNATIONAL COOPERATION AGENCY
TOKYO, JAPAN

Fig 4-9

the western area at the intersection of Line-1 and 3, and in the western area of No.81 on Line-4. And in these areas, it seems there is a great possibility that the high temperature geothermal fluid exists.

4-6 Discussion

4-6-1 Comparison with the Results of Geological Survey

The geological structure and the resistivity will not necessary correlated as expected, but from the data obtained in the survey area this time, the geological structure and the resistivity are correlated as follows:

Zunil Water Fall Lava	2,000 - 10,000 Ω m
Old Volcan de Zunil Lava	700 - 1,900 Ω m
Almolonga Lava	180 - 400 Ω m
Zunil Formation	60 - 400 Ω m
Alluvial deposits	30 - 50 Ω m

When the above classification is compared with the result of the measurements of the resistivity of rock samples (ref. Table 4-1), the resistivities of rock samples are lower than the above classification as a whole. It seems that the resistivity of rock samples were measured at higher moisture content than at the site.

From the result of the analysis and the above classification, the distributions of volcanic lavas are as follows:

Zunil Water Fall Lava is distributed only on the hills of the west side of the Samala River, and has a thickness thinner than 100m. Almolonga Lava is distributed widely on the west side of the Samala River. On the hills, it is covered by Zunil Water Fall Lava, and its thickness is uniform at about 100m.

Old Volcan de Zunil Lava were confirmed to exist mainly on the east side of the Samala River, and it is assumed to be distributed widely in this survey area.

4-6-2 Comparison with the Result of Seismic Survey

As mentioned above in 4-2-4, the measuring Lines are the same lines, as Line-1 and Line-A, and Line-3 and Line-B and C used by both the seismic as well as the electrical survey. Therefore, it is possible to compare the result of this survey with the seismic survey.

In order to interpret the underground structure, as the resistivity of the electrical survey and the elastic waves of the seismic survey were used, often the differences occur in interpretation, due to different physical properties of the rocks and layers.

(1) Line-1 (Line-A)

The existence of the fault between No.63 and No.71 was assumed according to the results of the seismic survey and confirmed by the electrical survey, but the near No.40, assumed by the results of the seismic survey, was not confirmed by the electrical survey.

The L_1 Horizon practically coincides with the interface of the resistivity layers corresponding to Zunil Water Fall Lava and Almolonga Lava with the 3rd layer.

The uplifted layer with the resistivity of more than 300 Ω m located between No.71 and No.85 coincides with the low S/N zone confirmed by the seismic survey. The uplifted layer differs from the granodiorite and it seems to be an unknown lava, which is not exposed as an outcrop on the surface.

(2) Line-3 (Line-B and C)

Similar to Line-1, the existence of the fault between No.21 and No.31 on Line-3 was assumed on the basis of the seismic survey. The fractured zone (fault) near No.20 on the east side of the Line-C located by the seismic survey was not confirmed by the electrical survey, as it was beyond the east end of the Line-3. But it seems that it is an extension of the fault assumed by the electrical survey located between No. 71 and No. 81 of Line-4. On the east side of Line-3, the differences are noticed between both survey methods, that is, the 3rd layer has the relatively low resistivity of 12 to 20 Ω m. Whereas, according to the seismic survey it has indicated a very high velocity of 4,500 m/sec.

As a conclusion, the low resistivity area of 12 - 20 Ω m detected as corresponding to the third layer is probably affected by the low resistivity zone near the surface nearby the Samala River. Therefore, the high velocity layer of 4,500m/sec detected by the seismic survey should be considered as being hidden without detection by the electrical survey, due to the local disturbances, as mentioned above.