REPUBLIC OF GUATEMALA

REPORT ON
GEOTHERMAL POWER DEVELOPMENT PROJECT

OCT. 1973

OVERSEAS TECHNICAL COOPERATION AGENCY
GOVERNMENT OF JAPAN

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PREFACE

The Government of Japan, in response to the request of the Government of the Republic of Guatemala, undertook to conduct a study for the geothermal power development project in the Quezaltenango area, the Republic of Guatemala, and entrusted the execution of the study to the Overseas Technical Cooperation Agency.

Being cognizant of the importance of geothermal power development project in the light of Five Year Development Plan of country as well as of social and economic significance of infrastructures as a basis for development, the Agency organized a survey team comprising seven members, headed by Dr. Tatsuo Yamasaki, Prof. Kyushu University, and dispatched it to Guatemala for a period of 30 days from February 27, 1973.

Thanks to the kind cooperation of the Government of the Republic of Guatemala and I. N. D. E., the study could have been carried out quite satisfactorily.

On the basis of the interim report, which was submitted while the team was in Guatemala, the team made again a comprehensive study of the data, information and samples gathered after its arrival in Japan, and thus the final report is now ready for presentation here.

Should this survey contribute to the friendship and rapprochment between Japan and the Republic of Guatemala, and economic exchange between the two countries, there would be nothing more rewarding.

In closing, I, on behalf of the O. T. C. A., would like to take this opportunity to express my sincere gratitude to those concerned in the Government of the Republic of Guatemala and I. N. D. E. for the whole-heated cooperation and support extended to us in the execution of the team.

October, 1973

K. Tatsuke

Keiichi Tatsuke
President Director General,
Overseas Technical
Cooperation Agency

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Mr. Keiichi Tatsuke, Director General
Overseas Technical Cooperation Agency
Tokyo, Japan

Dear Sir :

We take pleasure in submitting herewith the report of the preliminary studies on the Geothermal Power Development project in Zunil Area in the Republic of Guatemala. The survey team Comprising seven specialists of the West Japan Engineering Consultants, Inc. by virtue of the cooperation by Dia Consultants, Inc. and Japan Heavy Chemical Indnstries Co., Inc., was dispatched by the O. T. C. A. to the Republic of Guatemala.

The team made preliminary geothermal surveys in the Quezaltenango Area (especially in the Zunil Geothermal Area) based on the basic program of the Government of the Republic of Guatemala, and also made surveys of Moyuta Area in Guatemala and Ahuachapan Area in El Salvador in order to grasp the general geothermal manifestations in connection with this area. The team made the study of the stratigraphy, the geologic structures and the characteristics of the fumarolic steam and thermal water in Zunil Area, made theoretical studies based on the laboratory analyses of the collected samples, formulated the plan of future studies, and prepared this report.

In conclusion, the Zunil Area is one of the geothermal areas with the most dominant geothermal manifestations in Guatemala, and it is probably a very promising geothermal area of hydrothermal type, judging from the scale and mechanism, chemical characteristics, geologic structures of the geothermal system, etc. and we believe that this is a project worthy of advancing further studies for the development.

We take this opportunity to express deep gratitude to the officials of the Government of the Republic of Guatemala and the related Government Agencies, the President of INDE and his staff, H. E. Ambassador Junzo Mori and Councilor Akira Tsujino and other staff of the Japanese Embassy, for thier kind assistance to the survey team during the survey.

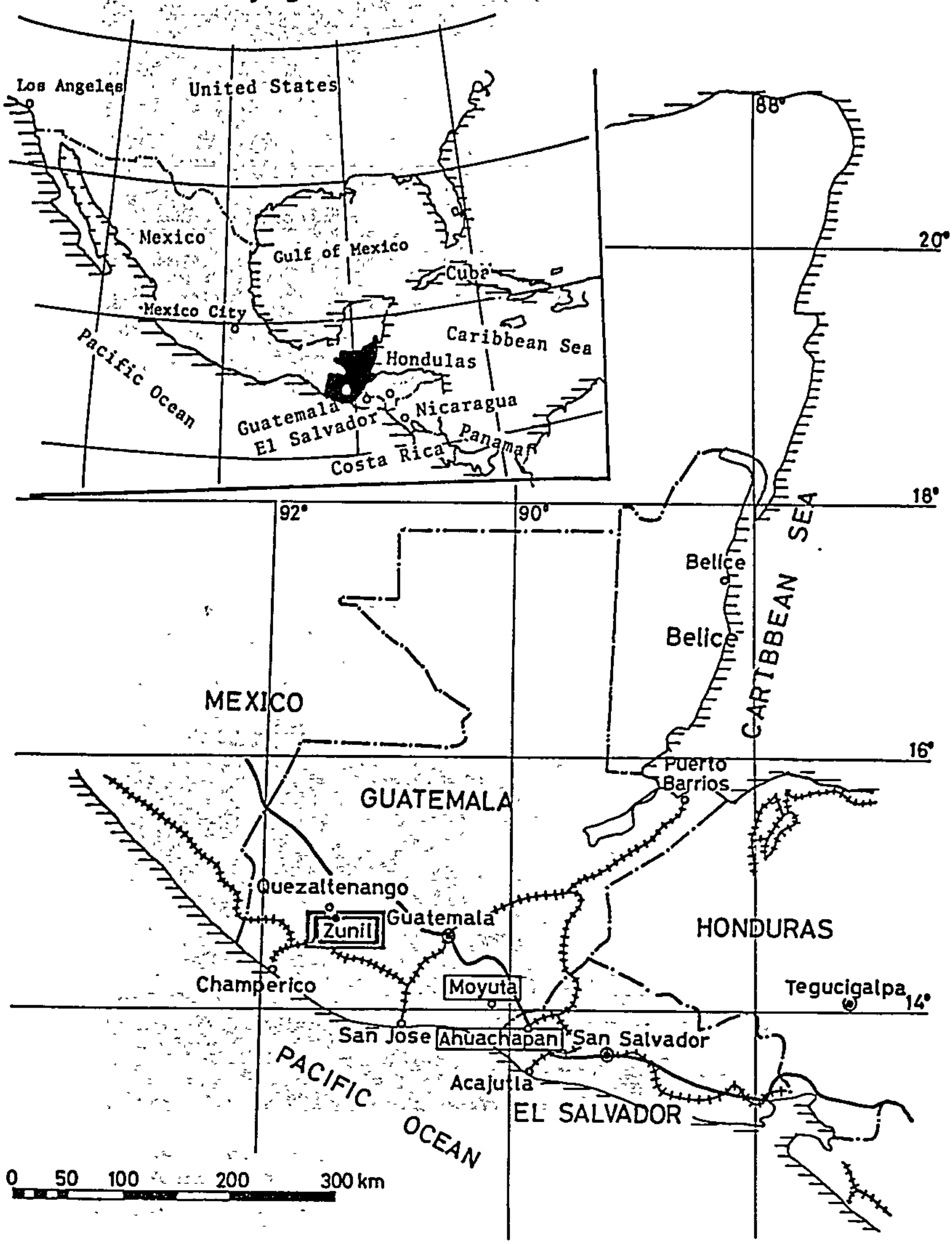
Yours sincerely,

T. Yamasaki

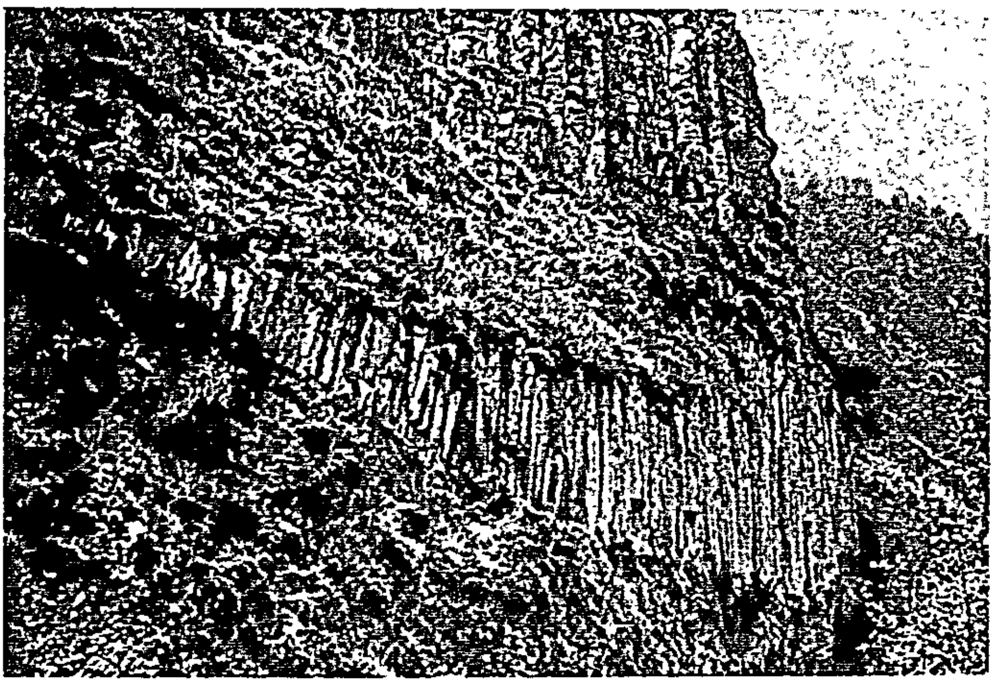
Tatsuo Yamasaki
Leader, Japanese Survey Team
for Geothermal Power
Development Project in the
Republic of Guatemala

Location Map

Surveying Area of Guatemala



A view of the Samala River Canyon loking from upper stream. The right side of the canyon consists of Zunil water-fall lava and the left side is steep cliff of rhyodacite occurred by the intrution of Cerro la Pedrera lavas. The planation surfaces of left and foreground sides are composed of pyroclastic flow deposit which are the lower formation of Zunil group. The N-E fault is running on the foreground side (north side).



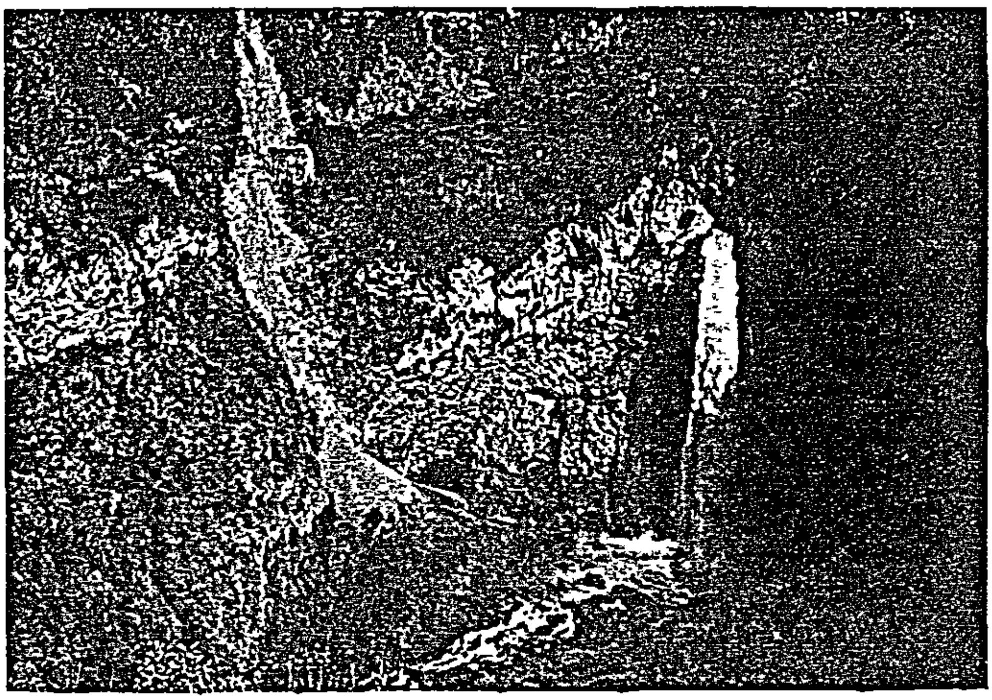
Columnar joint of pyroxene andesite lava flow, Middle formation of Zunil Group

Relief map of Guatemala

A view of the down stream looking from the Zunil water-fall.

The right side consists of Zunil water-fall lava and left side consists of pyroclastic flow deposits which are the Lower formation of Zunil group. The planation surface composed of these strata is looked to be two steps because the foreground side is fallen down by the N-W fault. There are somegeyers in a down strem of the canyon.

Zunil village and Santa Maria Volcano (3,790 m) Hotsprings gush out here and there along the side of the samala River flowing through Zunil village.



Zunil water-fall hang on the Zunil water-fall lava which is cut by the fault running N65°E. The fault falls down to the north (upper stream side) and its fracture zone is collapsed.

CONCLUSIONS

1. Proceeding of Survey

The survey team for the geothermal power project in the Republic of Guatemala left Tokyo on February 27, 1973 and returned to Japan on March 28, 1973 as scheduled.

During this period, the survey team made a field survey in the Zunil geothermal area situated approximately 10 km southeast of Quezaltenango city, which was the main object of the team, and obtained general information concerning geothermal phenomenon, hydrothermal system, volcano stratigraphy and geologic structure in the area. In addition, the mission also made a general view for several days at the Myuta geothermal area in the eastern part of the country and the Ahuachapan geothermal area in the neighboring El Salvádor, both of which belongs to the same volcanic chain as the Zunil geothermal area. In addition, the geochemical group of the team surveyed roughly the following geothermal areas in Guatemala.

San Marcos geothermal area west of Zunil; Amatitlan geothermal area west of Guatemala city; Ixpaco, Asuncion Mita and El Coco geothermal areas in the vicinity of Moyuta.

Despite the limited survey period, the team was able to gather a number of new data and obtain excellent results beyond expectation for a preliminary survey, thanks to the streneous efforts made by its members. Samples of rocks (about 150 pieces), altered minerals, hot-spring water and fumarolic condensed water collected during the survey were given a close study in the laboratory with X-ray diffraction analysis, chemical analysis and polarized microscopic analysis after the mission returned to Japan.

While a detailed study and analysis are still in progress, a summary of the results obtained so far will be given hereinafter. Since the results of these studies serve as important basic data for the subsequent surveys, they will be described fairly in detail and problems awaiting solutions in the future will also be pointed out.

2. Volcanic Province and Geothermal Areas in Guatemala

Guatemala may be divided into the following four physiographic provices from north to south: (1) Peten Lowland, (2) Central Guatemalan Cordillera, (3) Volcanic Province and (4) Pacific Coastal Plain (Refer to Chapter III)

Of these four provinces, the Volcanic Province belongs to Cenozoic Pacific Volcanic Zone of nearly southeast trending through Central America and is rich in active volcanoes, hot-springs and geothermal phenomenon. For this reason, Guatemala is considered to be one of the major volcanic countries and stores rich geothermal resources as untapped thermal energy resources.

From a combination of the distribution of pre-Tertiary basement rocks forming the so-called "inliers" or "fensters" of various widths and the Bouguer anomaly map, a large scale basement depression about 300 km long and 10 km wide with nearly southeast trending in the Volcanic Province is presumed. This depression is conveniently called "Guatemala-Quezaltenango depression (Refer to Chapter III, 3-3). This depression is considered to link with the Central graben in El Salvador and the Nicaragua depression, both of which belong to the same Pacific Valocanic Zone.

Mainly along the southern periphery of this depression develops a row of Quaternary volcanoes, part of which is still active today. Geothermal areas in various part of Guatemala are closely related with these volcanoes whose post volcanic activity are supplying geothermal fluids. A very thick layer of Neogen Tertiary volcanic rocks which fill up this depression provide geothermal reservoirs in these geothermal areas. There are a number of geothermal areas in the world which were formed exactly in the same way as a result of volcanic activities associated with grabens or depression filled with younger Cenozoic formation (Refer to Chapter III, 3-3).

All of the leading geothermal provinces in Guatemala including the Zunil, Moyuta and San Marcos geothermal areas have these geologic backgrounds in general.

3. Zunil Geothermal Area

3-1. Summary (Conclusions)

There is an extensive geothermal manifestation in areas around Zunil village which is about 8 km southeast of Quezaltenango city. These areas, called Zunil geothermal area collectively, should be defined a new and reclassified into smaller divisions after making clear their geologic structures, geothermal mechanism and extent with the progress of future surveys. The most active geothermal manifestation is observed in Fumarole Grande at the bottom of a deep gorge of the Samala river about 1.5 km south of Zunil village and in the area including Fumarole Negra adjacent to Fumarole Grande in the east.

The geology of this geothermal area consists mainly of three formations: 1) basement granitic rocks (Mesozoic), 2) overlying Zunil group (Tertiary volcanic rocks) and 3) intrusive and overlying Cerro Quemado group (Quaternary volcanic rocks).

Of these formations, some of permeable pyroclastic rocks of Zunil group may be considered to be geothermal reservoirs and their overlying compact lavas may frequently act as cap-rocks. As to the reservior, also the plain of uncomformity between Zunil group and its basement granitic rocks are being given special attention. As a passage of geothermal fluid, mainly the NE-EW trending fault system and fissures developed around rhyodacites (Quaternary volcanic rocks) domes or intrusive bodies of various scales are conceivable. Moreover, the present activities of the area may be presumed to be provided by the post-volcanic activities of active Cerro Quemado which until recently were erupting lavas.

Fumarole Grande has a geyser with a large yield containing a large amount of deep thermal water. Besides, very active fumaroles, hot-springs and strongly altered zones have been confirmed in the surrounding area. The area extends over 1 - 2 km^2 and shows well developed silicified rocks which suggest the possibility of deep thermal water in addition to its dynamic geothermal activities (Refer to Chapter IV, 3). Also judging from chemical properties of hot-spring water and fumarolic gas (Chapter V, 3-1) a promising geothermal reservoir of the neutral-slightly alkalinesaline spring type is presumed to exist under the ground. For this reason, a great hope is placed on the development of this area as potential geothermal field of the so-called "hot-water system".

Besides, a number of hot-springs are distributed along the Samala river which runs through Zunil village in the north, while such geothermal manifestations as Aguas Amargas and Fuentes Georgias hot-springs, fumaroles, altered zones and Sulphur Mine are deployed extensively in the south.

In summary, the Zunil geothermal area is equipped with very favorable conditions in respect of its functions such as the extent, geothermal manifestations and mechanism of geothermal system. In particular, the most prominent geothermal activities, is concentrated in an area, including Fumarole Grande and Fumarole Negra, extending over 1 - 2 km^2 in width. This area is considered to become the first object of geothermal development.

Its topography is generally rugged and complicated being strongly eroded by the Samala river which runs through the area forming a deep V-shaped valley. However, the right bank is relatively spacious and forms a comparatively flat lava plateau, which is suitable for the deployment of a site of the future geothermal power plant and for drilling wells. Besides, the highway traversing the plateau is completely paved and the area is conveniently located as a whole.

It is of course difficult to predict the amout of reserved geothermal energy in figures in this stage of preliminary investigation. It is believed, however, that the area is well worthy of continued survey with the aim of developing at least 30 MW, the minimum unit of economic operation of a geothermal power plant at present, as the goal of phase I of the development project.

Therefore, the emphasis of the subsequent survey should be placed on this area and a plan should be worked out immediately for exploratory borings while continuing the present geological, geophysical and geochemical prospecting also in the future. It is needless to say that the geology and other conditions of the entire Zunil geothermal area around this field should be clarified in parallel and in conjunction with the study of this geothermal field.

Because of characteristics of geothermal resources, the qualitative and quantitative assessment of a geothermal field and its development can take a concrete form and finalize when the work progresses from exploratory drillings to the drilling of test wells or even production wells at times. Therefore, the survey of the Zunil geothermal field should be continued with the aim of attaining exploratory drillings or drilling of test wells at the least.

The following is a summary of findings of a survey and analysis of the Zunil geothermal area.

3-2. Volcano Stratigraphy

The geology in and around the Zunil geothermal area may be divided largely into aforementioned three formations - U. basement granitic rocks, 2). overlying Zunil group (newly named to Tertiary volcanic rocks), and intrusive and overlying Cerro Quemado group (newly named to Quaternary volcanic rocks).

(1) The Zunil geothermal field and its surrounding area is overlain extensively by Tertiary and Quaternary volcanic rocks. The basement granites outcrop locally as the "inliers" of various sizes in the area extending from the survey area to the north and south to Lake Atitlan. Also, the granites were confirmed at a depth of 250 - 320 m by exploratory drillings (Jolm - No. 1 and others) at a point about 7 - 12 km northeast of Zunil provided

under the hydroelectric development project for Lake Atitlan. On the basis of these data, it is assumed that there is distribution of mainly Cretaceous granites at a relatively smaller depth under the ground of this geothermal field.

Since there is distribution of the lowest and lower formations of Zunil group on the left bank of the Samala river around Fumarole Negra, it is assumed that the basement (granitic rocks) in this area is at the shallowest point. The shallow besement is not desirable for a geothermal field. On the right bank of the Samala river, on the contrary, the basement gradually becomes deeper owing to a fault system.

(2) Zunil group corresponds to part of Tertiary volcanic rocks filling up the previously mentioned Guatemala-Quezaltenango depression. The total thickness of the formation confirmed by the present survey in this area is about 500 m, but the upper and lower limit have not yet clarified.

This group comprises mainly andesitic lavas, tuffs, tuff breccias and pyroclastic flow deposits, of which mainly the permeable pyroclastic rocks and at times the lavas with well developed joints and fissures may probably be geothermal reservoir while their overlying compact lavas seems to be cap rocks.

The geologic succession of Tertiary volcanic rocks in Guatemala including the Zunil group is not known in detail. However, clarification of geologic succession of these volcanic rocks is an important Problem for the determination of geothermal reservoirs, cap rocks and geologic structure of the geothermal field. While the Zunil group, part of the Tertiary volcanic rocks, was divided tentatively into four formations under this survey, a more detailed study should be made in the subsequent detailed survey.

It is easily assumed that the unconformity plane at the base of the Zunil group often overlains the relict weathered surface of basement granites and the boundary between the two is worthy of attention as a geothermal reservoir.

(3) Cerro Quemado group forms huge lava domes, strato volcanoes and lava flows around the geothermal field. It is assumed that the post volcanic action of Quemada volcano group adjacent to the geothermal field in the west, which was very active until recently, provides geothermal fluids. Besides, remarkable geothermal phenomena such as geysers, fumaroles, hot-springs, and altered zones around Cerro la Pedrera lavas consisting mainly of highly viscous rhyodacites which often form domes of various

sizes are noteworthy. These are probably the result of major cracks and joints developed in the vicinity of rhyodacites bodies due to their intrusions, thus providing a passage for thermal liquid.

The Zunil waterfall lava which flowed from the southeast base of valcono Quemado and formed a fan-shaped lava plateau has a thickness of 100 - 150 m and overlains the dominant geothermal field on the right bank of the Samala river including Fumarole Grande, thereby impeding the progress of the survey. This group should be studied more closely into its history of volcanic activities.

3-3. Geologic Structure and Geothermal System

Following the confirmation of general volcanic stratigraphy of the Zunil geothermal field, on 1/50,000 geologic map (Fig. IV-1) was compiled, from which the geologic structure and mechanism of geothermal system was schematicaly shown as a explanatory dyagram (Fig. IV-3). After returning to Japan, the survey mission analyzed air photographs of the area to examine faults and fractures, though not in details and confirmed that the findings of the analysis of air photographs almost coincides with the results of the field survey (Refer to Chapter II).

This area apparently has two fault systems; one is trending nearly EW or NNE and the other is trending NE or NNE. Generally speaking, the former is related to Guatemala-Quezaltenango depression and the latter is corresponding with the faults traversing the formerand bordering the Guatemala city graben. These major faults and accompanying sub-faults or fractures are considered to have provided the present passage for lava and thermal fluid.

Since the Zunil group, the main geothermal reservoir, generally dips slightly toward north, its upper and upper formations in order expose toward north from the area including Fumarole Grande and Fumarole Negra in the south. Thus in the south, of the area, there crops out mainly of the lower formation and, in particular, the left bank of the Samala river including Fumarole Negra shows exposure of the lowest formation. As a result, the depth of basement rocks in this area may be assumed to be shall owest.

The greater part of this basement rock, however, is depressed gradually in steps toward Quemado volcano owing to the previously mentioned faults showing NW of W downthrown wings. It is very sensible to assume that the area of Quemado volcano, after the erupting a huge volume of lavas, sank by itself afterward. Therefore, the right bank of the Samala river including Fumarole Grande has a deeper basement rock, showing favorable conditions as a geothermal field.

Many of rhyodacite domes and intrusive bodies scattered in the geothermal field with the fractures and around them are providing a passage for thermal fluids, as previously mentioned, and these intrusive bodies themselves are considered to have intruded along the fault systems.

Moreover, the termal source of the geothermal area is presumed to have been provided as a result of post volcanic action of Quemado volcano as previously mentioned.

3-4. Hydrothermal Alteration

Samples of altered rocks, collected spontaneously in the Zunil, Moyuta and Ahuachapan geothermal areas during the limited survey periods, were examined for the determination of mineral constituent mainly by X-ray diffraction analysis and of pH value of immersion solution of altered rocks (Refer to Chapter IV, 3). Although a more detailed analysis is required in the future with close follow-up of altered zones and additional samples, it was able to comprehend the general characteristics of each geothermal field surveyed from the findings of this analysis.

In general, hydrothermal alteration of typical acidic type was frequently observed. Characteristic minerals contained are cristobalite, quartz, alunite and kaolin. Also mixed in these samples at times is the so-called "silicified rock" containing a large amount of cristobalite or quartz. Development of silicified rock is an indication of the possibility of deep thermal water under the ground.

Because of the fact that the Zunil geothermal field including Fumarole Grande and Fumarole Negra often shows well developed silicified rocks and also gives pH values of immersion solution within the range of 3 4, a reserve of powerful high temperature deep thermal water of the neutral slightly alkaline type can be expected. For this reason, the area is considered to be the most promising geothermal field for development.

On the other hand, however, the immersion solutions of altered rocks in the area including two acidic hot-springs - Fuentes Georginas (pH value of 2) and Aguas Amargus (pH value of 2. 2) - and also Sulphur Mine in the southeast show abnormally high acidity with pH value of $\pm$ 1. 0. Since the neutral-alkaline deep hot water often oxidizes near ground surface and shows strong acidity in the fumarole and altered zone on the surface, a hasty conclusion should not be made on this point. However, this abnormal pH value in the wide range of area is noteworthy. There is a possibility, therefore, that deep hot water in this area is acidic and unsuitable for geothermal power generation.

3-5. Geothermal Geochemistry

For the so called "hot-water system" which has a high yield of high temperature deep hot water of the neutral saline (Chloride) type, analysis of hot-spring water is an effective means to determine the temperature and nature of geothermal reservoirs under the ground. However, the deep hot water was obtained only from three geothermal fields - geyser in Zunil, San Marcos (at three locations) and south shore of Lake Amatitlan (at several locations) out of the 36 samples collecte from each of the previously mentioned geothermal areas.

For this reason, the following methods (Refer to Chapter V, 2) under development by Koga, a member of the mission, were also used experimentally aiming mainly at the study of hydrothermal steam system vapour-dominated system without hot water in locations centering on fumaroles.

(1) Analysis of fumarolic gas; The nature and other characteristics of hot water may be determined from the concentration of CO_2 and H_2S and the CO_2/H_2S ratio.

(2) Analysis of fumarolic condensed water; High temperature zone of geothermal field may be determined from the concentration of volatile substances suck as HBO_2, NH_4, Hg, F etc.

(3) Measurement of the amount of mercury contained in altered rocks (soils); High temperature zone of the underground may be traced from the concentration of Hg contained in altered rocks and sediments of hot-spring water.

As a result of the study using these methods, the following conclusions have been reached.

Though the Zunil geothermal area is large in scale and rich in geothermal manifestation at various locations, a high yield of high temperature thermal water containing deep hot water is available only from the geyser in Fumarole Grande and the rest of thermal water is produced at shallower formations by heating. This is probably because the flow of hot water is hindered by local geological conditions.

However, a predominant geothermal reservoir is presumed to exist under the ground judging from the nature and scale of geothermal manifestation accompanied by active fumaroles, strongly altered zones and many hot-springs in addition to the geyser. On the basis of this fact, the area is considered to be a promising geothermal field.

This geyser is saline spring type with a pH value of 9.0 and Cl content of 713 ppm. From the Na/K ratio and the concentration of SiO_2, the temperature of deep hot water under the ground was roughly estimated to be 180 ~ 215°C. Judging from the nature of fumarolic gas, the deep hot water is presumed to be that of the neutral-slightly alkaline saline spring type. This assumption is consistent with the assumption made on the basis of the altered minerals (Refer to Chapter IV. 3-1).

From a study of fumaroles located at the highway traversing Fumarole Negra and Zunil Water-fall lava in the west for the content of HBO_2, NH_4 and Hg (No measurement was made of F during this survey) in the previously mentioned fumarolic condensed water, a high temperature zone in the underground was also presumed. Besides, the maximum Hg concentration of about 200 ppm was detected from the altered rocks in Fumarole Negra, which also supports the bright prospect of the area. Since it has been confirmed that the Hg measurement is most effective to trace a high temperature zone, it is desirable to apply this method more frequently in the subsequent detailed survey.

4. Development of Geothermal Areas

A number of geothermal areas belonging to a series of Central American-Pacific volcanic belt are distributed sporadically in almost southeast direction across Guatemala besides the Zunil geothermal area, as previously mentioned. Among these geothermal areas, only the Moyuta geothermal areas in the eastern part of Guatemala and the Ahuachapan geothermal area in the neighboring El Salvador are under plan for development. In each of these two geothermal areas, Tertiary volcanic rocks comparable to Zunil group provide a geothermal reservoir and thermal fluids are supplied by the post volcanic action of a huge dome volcano which intrudes and overlies this reservoir. In these cases, fault systems cutting through Tertiary volcanic rocks and fractures accompanied by small scale intrusive bodies are considered to provide a passage for thermal fluids. The surface geothermal manifestation is most prominent in the Ahuachapan geothermal area where a number of exploratory wells and production wells have been drilled so far and well No. 12 is being brilled at present. A plan for generation of about 30,000 KW of power has been finalized and the work is now under way.

The altered rock obtained from core samples in the Ahuachapan geothermal field, brought to Japan for analysis, comprises wairakite, calcite and chlorite and almost correspond with the altered rock of the neutral slightly alkaline type found in Otake field in Japan.

In the Moyuta geothermal area, a survey is being conducted mainly with the cooperation of a U. S. consultants firm and a joint survey by INDE and D. G. M. H. is also under way at present. A survey of geothermal manifestation and a geological survey on the basis of 1/50,000 scale maps have already been completed and an exploratory boring to a depth of 300 m is being carried out. Preparations are now under way for electric prospecting. As no samples of deep hot water were available in the Moyuta area, because surface geothermal manifestations appear in young lavas overlying the reservoir, it is difficult to make accurate prediction as to the state of deep substratum. However, the following assumption is made from the findings of a field survey and results of analysis of samples.

(1) Samples of altered rocks obtained from the Guinea field and Marcuccy field in the Moyuta geothermal area have confirmed mineral constituents of cristobalite, montmorillonite, stilbit and gypsum and their immersion solution have shown a pH value of 2-3. However, there was a poor content of alunite which is characteristic of acidic fumaroles and solfatra. From this, it may be said that this geothermal field has characteristics of a geothermal zone that produces ordinary neutral-slighty alkaline deep hot water.

Altered rocks (sampled at elevation of 740 - 900 m) contain wairakite and laumontite and the immersion solutions show a pH value of 6 - 7. Silica minerals comprise solely of quartz and show no content of cristobalite which is formed at low temperatures.

From this, it is assumed that the altered rocks of this outcrop was formed originally in the deep under the ground and was then exposed to the surface due to faulting or erosion. It is almost certain that the deep hot water which had occurred this process was of the neutral-slighty alkaline type.

(2) While the Moyuta geothermal field showed active geothermal manifestations no samples of deep hot water that provides a clue to the determination of temperatures of substratum were available from this area. Though some hot-springs showed a high temperature of about 90°C, most of hot-spring water in this area is groundwater heated by fumarole at a shallow stratum. This assumption is also supported by the findings of analysis of fumarolic condensed water.

Judging from the fumarolic gas, the deep hot water, if any, will be of the slighty alkaline saline type as is the case with Zunil. In view of a considerably high concentration of Hg in the altered rocks in the Azulco field and also a high content of Hg in fumarolic condensed water in the Guinea and Marcuccy field, it is assumed that the substratum has a considerably high temperature.

For the Moyuta geothermal field, the methods of studies of vapour-dominated systems with particular emphasis on the measurement of Hg is considered most effective. In general, the Moyuta geothermal area resembles the Ahuachapan geothermal area in many points such as the scale, geothermal activities, altered zone and geologic structure and is considered to be a promising geothermal field.

Other features of geochemical prospecting in other geothermal areas may be three samples of deep hot water obtained in the San Marcos geothermal area showing a high concentration of SiO_2 and Li, which is an indication of high temperatures in the substratum. The deep hot water is assumed to be of the slighty alkaline saline type. Judging from the concentration of SiO_2 and Na/K ratio, the deep hot water is assumed to have a temperature range of 220 - 230°C. Therefore, this area is considered to have a high temperature geothermal reservoir under the ground and will be one of the potential geothermal development areas in the future.

Samples containing deep hot water were also obtained at several locations on the south shore of Lake Amatitlan. The concentration of SiO_2 and Na/K ratio indicated the possibility of hot water of about 200°C.

CHAPTER I INTRODUCTION

1. Purpose of Survey

The purpose of this survey is to make a preliminary survey of the basic facts related with the feasibility of the geothermal power development project for Quezaltenango Area of the Instituto Nacioral de Electrificacion (INDE) by dispatching the thechnical survey team by the request of the Republic of Guatemala.

The Republic of Guatemala is trongly desirous of obtaining technical and economic assistance from Japan for a prompt materialization of the said geothermal power development.

2. Scope

The scope of this report covers the geological field reconnaisance, study of characteristics of the fumarolic steam and thermal water, collection of samples, etc. in Zunil are: about 8 km southeast of Quezaltenango City, Quezaltenango State, located approximately 200 km to the west of Guatemala City, and rough surveys of Moyuta, San Marcos, Atitlan, Ixpaco and Asuncion Mita geothermal areas in Guatemala and Ahuachapan area in El Salvador, for general geothermal manifestations in connection with the said area.

3. Background

The Government of the Republic of Guatemala makes it the most urgent basic economic policy to stabilize the welfare of the people and to develop industries, and especially it gives the highest priority to an early strengthening of electric power as the basis for the industrial development. It also puts stress on the effective utilization of the domestic energy resources. In this connection, the Government made the geothermal power development project for Zunil area to develop the ample geothermal potential in the country, and requested technical and economic assistance from the Japanese Government.

The Japanese Government entrusted to the Overseas Technical Cooperation

Agency (O.T.C.A.) to conduct the field survey of the project. And the O.T.C.A. organized the survey team comprising members from the West Japan Engineering Consultants, Inc., the Dia Consultants, Inc., and the Japan Heavy Chemical Industries Co., Inc., and dispatched it to Guatemala.

4. Members of Team and Their Assignment

	Name		Assignment
Leader	Tatsuo YAMASAKI	Advisor, West Japan Engineering Consultants, Inc. Professor of Kyushu University	General
Member	Akito KOGA	Advisor, West Japan Engineering Consultants, Inc. Professor of Kyushu University	Geochemistry
Member	Yukio MATSUMOTO	Advisor, West Japan Engineering Consultants, Inc. Professor of Nagasaki University	Geology
Member	Hisayoshi NAKAMURA	Deputy Director, Geothermal Division, Nippon Heavy Chemical Industries, Inc.	Geology
Member	Kenichi WATANABE	Chief Engineer, Dia Consultants, Inc.	Geology
Member	Yasuhiko EJIMA	Thermal Power Dept., West Japan Engineering Consultants, Inc.	Geothermal Power Development
Member	Junichi YAMAZAKI	Tokyo Office, West Japan Engineering Consultants, Inc.	Electric Power in General

5. Itinerary of Survey Team

1973

February 27 (Tue.)	Left Haneda, Tokyo.
February 28 (Wed.)	Arrived in Guatemala City.
March 1 (Thu.)	Conference with Japanese Embassy, Preparation for conference with INDE.
March 2 (Fri.)	Conference on survey with INDE and Mining Bureau (DGMH); discussions and data collection.
March 3 (Sat.)	Preparation for the field survey and data collection.

March 4 (Sun.)	Survey of Amatitlan Geothermal Area.
March 5 (Mon.)	Survey of Moyuta Geothermal Area.
March 6 (Tue.)	Survey of Moyuta Area and entered El Salvador.
March 7 (Wed.)	Survey of Ahuachapan Geothermal Area in El Salvador.
March 8 (Thu.)	Discussion with Comision Ejecotiva Hidro-electica del Rio Lempa (CEL); returned to Guatemala at night.
March 9 (Fri.)	Conference with Japanese Embassy for Survey of Zunil Area.
March 10 (Sat.)	Moved from Guatemala City to Quezaltenango City.
March 11 (Sun.)	Reconnaisance of Zunil Area.
March 12 (Mon.)	Geologic Survey and geothermal manifestations survey in Moyuta.
March 13 (Tue.)	Ditto.
March 14 (Wed.)	Geologic survey in Zunil Area; geothermal manifestations survey in San Marcos Area.
March 15 (Thu.)	Geologic survey in Zunil Area; geothermal manifestations survey in Amatitlan Area.
March 16 (Fri.)	Geologic survey in Zunil Area; geothermal manifestations survey in Ixpaco Area.
March 17 (Sat.)	Geologic survey in Zunil Area; geologic manifestations survey in Asuncion Mita Area.
March 18 (Sun.)	Interim discussions of survey data among team members.
March 19 (Mon.)	Geologic survey in Zunil Area; geothermal manifestations survey in Moyuta Area.
March 20 (Tue.)	Geothermal survey in Zunil Area; review of survey results.
March 21 (Wed.)	Moved from Quesaltenango City to Guatemala City.
March 22 (Thu.)	Preparation of field report; conference with Embassy.
March 23 (Fri.)	Preparation of field report.
March 24 (Sat.)	Presentation of field report to INDE and explanation.
March 25 (Sun.)	Collection of survey instruments and data and packing.
March 26 (Mon.)	Left Guatemala City.
March 28 (Wed.)	Arrived at Haneda.

6. Acknowledgement

The Team takes this opportunity to express its deep gratitude to the Government of the Republic of Guatemala and its Agencies for their kind cooperation and assistance extended to the Survey Team during the survey. Special acknowledgement is made of the willing cooperation of INDE for their kind arrangement to let their engineers accompany the Survey Team and to provide many conveniences, and of the cooperation and many data made available by the following organizations.

(1) Direccion General de Mineria e Hidrocarburos (DGMH), Guatemala

(2) Instituto Geografico Nacional (IGN), Guatemala

(3) Comicion Ejecutiva Hidroelectica del Rio Lempa (CEL), El Salvador

Mr. Junzo MORI, Japanese Ambassador Extra ordinary and Plenipotentiary in Guatemala and his staff were so kind to extend very thoughtful and appropriate guidance and strong support to the Team, for which the Team expresses sincere gratitude.

CHAPTER II OUTLINE OF GUATEMALA

1. Area

The Republic of Guatemala is situated in the northern extremity of the Central American Isthmus and borders on Mexico in the north and west, and Honduras and El Salvador in the southeast while facing the Pacific Ocean in the south. The country covers an area of 108,889 km^2, a little less than one-third of Japan.

2. Geographical Features

The central mountain range runs across the country from northwest to south-west, which is featured by many active and dormant volcanoes. Because of a large number of volcanoes, the country is subject to frequent earthquakes and the area in and around the capital city of Guatemala alone has suffered several severe earthquakes in the past.

With the central mountain range as the watershed, rivers take their course either on the east or the west slope of the range. Rivers flowing into the Pacific are all swift running rivers and are short in length and those emptying into the Caribbean Sea are comparatively long and large rivers, of which the Motagua and the Paz are navigable. Principal lakes are Lake Izabal, Lake Atitlan and Lake Amatitlan, all of which, being formed by volcanic activities, are famous for their scenic beauty.

3. Climate

Even though the country is within the Tropics, the climate varies greatly with the altitude. The lowlands along the coast have a tropical climate (25°C ~ 30°C) while the highlands are under a temperate climate (16°C ~ 20°C). The dry season prevails from Nobember through April and the rainy season lasts from May through October.

4. Population

Guatemala has a population of 5,369,000 (in 1971) with a population density of 50 persons/km^2 which varies greatly with localities. The growth rate of population is quite high at 3.3%. The urban population in 1971 accounted for 38% of the total population with the remaining 62% is accounted for by the agricultural population.

The population comprises the natives accounting for 67%, mixed races 25% and Caucasians of Spanish origin only 8%.

While the Spanish is used as the official language, such native tongues as Mayan and KITCHU are common languages used by the natives.

5. Economy

The Gross National Product (GNP) is 2,000 million dollars (in 1972) and the annual growth rate of GNP is 7% on the average.

Agriculture is the basis of the economy of Guatemala and about 68% of the population are engaged in agriculture. Since the farm products, particularly coffee and cotton have the largest share in the country's total exports, the nation's economy is greatly influenced by crop conditions and world market price of these products. To lessen such an effect on the economy, the Government is stiriving for the improvement of productivity and diversification of agriculture, as well as industrialization of the country centering on the development of power resources.

The currency unit in use is Quezal and one Quezal is equivalent to 100 Centavos. The exchange rate is pegged at one Quezal = one US dollar since 1924.

Commodity prices are stabilized and both the living cost index and the wholesale price index have shown little fluctuations in the past 10 years.

CHAPTER III OUTLINE OF GEOLOGY OF GUATEMALA

The Republic of Guatemala is far away from Japan with the Pacific Ocean lying between the tow countries. However, the two countries belong to the same Cenozoic Circum Pacific Orogenic, Earthquake and Volcanic Zone. In other words, the two countries are situated in the same Geothermal Zone from a world-wide view even though there is intermission between the two.

While the geology of Guatemala has many similarities in rocks, geologic structures, volcanism, geologic ages etc. to those of Japan and is a very interesting field, it is still unknown to the Japanese geologists. Geological informations of this country have increased considerably in recent years as a result of streneous efforts of Institute Geografico National, Guatemala (I. G. N) and other organizations concerned. From these informations a Geologic Map of Guatemala, 1/500,000, Bonis et al. 1970 has been compiled. As for regional data, "Geology of Quezaltenango Area with Geologic Map of Quezaltenango Region, 1/250,000, Bonis, 1965" for the Quezaltenango Region, which is adjacent to the Zunil Geothermal area under the present survey, has already been published. A prject for the compilation of 1/50,000 scale detailed geologic maps has been under way and accurate and valuable findings have been published frequently, though in a limited volume, with the cooperation of the American geologists. Besides, with the addition of Williams' (1960) valuable findings on Volcanic Province (Guatemala Highland) which is directly related to the geothermal areas, the geology of this country is being clarified gradually.

It was extremely difficult to make a detailed and correct geological summary over the whole Guatemala from limited data obtained during a short period of survey, which was not the main objective of this survey any way. Therefore, only the outline of geology of this country will be described here as a reference for the future survey. Besides, the mission was able to predict the existence of a large scale Guatemala-Quezaltenango depression with NW-SE trending in Volcanic Province judging mainly from a combination map of the distrubition of pre-Tertiary basements and the Gravity Bouguer abnormaly map (Fig. III-3). This depression is taken up for discussion here because it apparently has a linkage with Central graven in El Salvador and the Nicaragua depression and runs in parallel with the Pacific Volcanic Chain in Central America and controls geotectonics of geothermal province in Guatemala on the whole.

Guatemala is divided into the following four main physiographic provinces from north to south (Fig. III-1). (1) Peten Lowland ; Lowland in the form of a basin consisting mostly with thick Cretaceous and Tertiary deposits, (2) Central Guatemalan Cordillera ; Folded mountains with the geologic axes of east to west arc, convex to the south, comprising mainly Paleozoic - Mesozoic crystalline and sedimentary rocks associated with granites, (3) Volcanic Province ; Area belonging to NW-SE trending Cenozoic Pacific Volcanic Zone overlain by a row of Quarternary volcanic cones and (4) Pacific Coastal Plain ; Plain buried by a vast amount of clastic deposits produced from the erosion of Volcanic Province (Highland) to the north.

1. Peten Lowland and Maya Mountins

The Peten Lowland (or basin) which includes Peten province and Belice in northern Guatemala is a tropical lowland about 100m above sealevel comprising gently dipping Mesozoic (Mainly Cretaceous) and Tertiary sediments. This lowland Joints the Yucatan Platform deploying extensively in the Yucatan Peninsula of the neighboring Mexico and forms part of the peninsula. Most of this area completely dries up during the dry season. The area of the Cretaceous carbonate rocks forms a vast karst topography with continuous noked hills at elevations of 30 ~ 100m, while a vast Savannas area studded mainly with pines and at times with Jungles deploys extensively. This area is well known for its many relics of the once flourished brilliant Pre-Columbian Mayan civilization including Tikal, the capital of the ancient Mayan Empire. Today, however, the area presents a state of near-desert with almost no inhabitants and there is no accounting for the event of the old days. The cause of this decline of civilization in involved in mystery.

The geologic structures of Peten Lowland almost parallels with the Central Guatemala Cordillera in the south and shows a trend of approximately east-west arc, convex to the north on the whole. In other words, it forms a semi-basin structure trending the north. Accordingly, sedimentary deposits of upper layers in geological succession ranging from Cretaceous to younger Tertiary are distributed from the periphery to the center of the basin, while each stratum accompanied by facies changes increasing rapidly in thickness.

Cretaceous carbonates (Cobon, Ixcoy formations, etc.) transform into evaprate deposits comprising chemical limestones, gypsum, rock salt, patash salt etc., from the periphery of the basin toward the center and is presumed to have a maximum thickness of more than 3,000m.

Further to north, there is distribution of younger Tertiary deposits with a total thickness of about 1,000m toward the Yucatan Peninsula overlying these sedimentary deposits. These are almost horizontal formations and are either evaporate deposits or continental deposits which consisted mainly of limestones, gypsum, red beds, conglomerates etc. and intercalated with marine deposits in the lowest.

Since the southern part of the Peten Lowland has a chain of low ranges such as Sierra del Locandon and Montana de Chiquibul with NW-SE trending, which are frequently accompanied with gentl foldings, this area is also called Marginal Folded Belt and regarded as a transitional zone from the Central Cordillera in the south to Peten Lowland. In this area, the previously mentioned Cretaceous carbonates are overlain mainly by clastic rocks of the marine flysh type, called Sepur formation of Upper Cretaceous (Campanian) - lower Tertiary (Eocene). These rocks frequently contain a large quantity of serpentinite pebbles. Since the presence of these pebbles is not observed in the lower formations, the serpentinite bodies distributing along the Central Cordillera, which will be discussed in the next section, are considered to have appeared on the surface for the first time at the end of Cretaceous period when these clastic rocks began to deposit in the area.

In the Maya Mountain area to the east of Peten Lowland, there are outcrops of clastic rocks (with a maximum thickness of about 3,000m) of Pennsylvanian - Permian, which is older than the previously mentioned formations, part of which has been metamorphosed to crystalline rocks due to intrusions of granitic rocks (said to be 235 ± 35m y.). Maya mountains are cut across by faults in the south and north and form a large horst mountain in general.

Since the Peten Lowland is a waste land and is difficult of access, its geology is still not known completely. The stratigraphy mentioned so far has been pressumed from the findings of 10 borings for oil prospecting and other surveys. While no definite conclusions have been reached on the probable petroleum deposit, the sedimentary rocks in this area is estimated to have a maximum thickness of 10,000m. A further study will probably be made on the petroleum possibility in the future.

2. Central Guatemalan Cordillera

A group of steep mountain ranges lying across Central Guatemala and extending with east to west arc, trending same as the Peten Lowland, is termed Central Guatemalan Cordillera. From Chiapas Province of Mexico in the west and from Honduras in the east, this Cordillera is considered to extend through northern Nicaragua to join part of the geotectonic axis of Great Antiles far off in the Caribbean Sea. Therefore, these are also called collectively as Sierra of

Northern Central America. Further, the Cayman (submarine) ridge of the Caribbean Sea, Nicaragua rise and also Bartlett trough (submarine trench, approximately 5,000 ~ 6,000m in depth) which is running between the two are considered to have close relations with the structure of this Cordillera.

The Guatemalan Cordillera comprises mainly Palaeozoic and Mesozoic metamorphic rocks; folded sedimentary rocks, granitic rocks and serpentinite. In this area two major fault systems - Motagua and Polochic - are traced almost in parallel with the east to west arc of the Cordillera. These fault systems run almost straight and form fault valleys bearing the same names which have eroded deep along the strongly disturbed zone. These faults apparently extend the afore-mentioned Bartlett trough in the Caribbean Sea. This trough is explained to have been formed by the taphrogenic movement associated with the orogenic movement which formed this Cordillera at about the same time. This Cordillera, cut by these two major fault systems, are divided into the following three groups.

2-1. Northern Group

In the area north of Polochic fault there is a chain of such mountain ranges as Cuchumatanes, Chama and Santa Cruz, which join Madre Oriental in Chiapas Province of Mexico. Geology of this area consists of the following formations in descending order.

Mesozoic :

Cretaceous	Ixcoy, coban formations (carbonates rocks)
Jurasic	Todos Santos formation (redbeds)

Upper Palaeozoic :

Permian	Chochal formation (carbonates rocks)
Pennsylvanian ~ early Permian :	Santa Rosa formation (clastic rocks)

In this area, crystalline metamorphic rocks of lower Palaeozoic, which are the basement rocks of Guatemala, are not found and instead, the Santa Rosa formation comprising mainly clastic rocks of upper Palaeozoic and its overlying Chochal formation comprising mainly carbonates rocks seem to consitute the core of this area. Following the deposition of these rocks, there was local deposition of Molassic Todas Santos redbeds of Jurasic in age after the Jaliscopan orogeny which occurred during the period from the end of Permian to Triassic. And, the later the area was overlain by the Cretaceous carbonates rocks as already mentioned.

In this area, large scale intrusion of granitic rocks or regional metamorphism due to the intrusion such as those observed in the Middle group, is not recognized. However, numerous serpentinite intrusive bodies some of which has an outcrop area of about 1,000 km^2 is known in Santa Cruz mountain range along the Polochic fault in the east.

The fold belt and metamorphic rocks in the Cordillera gradually change northward to the more gently folded Mesozoic and Tertiary sedimentary rocks in the Peten Lowland.

2-2. Middle Group

This is an area flanked by such two major fault systems as Polichic and Motagua and has Chacus, Minas and Mico mountain ranges extending frem Madre de Sur in Chiapas Province of Mexico.

In this area, the said upper Palaeozoic formations in the North Group crop out locally and the crystalline metamorphic rocks of lower Palaeozoic (Chuacus series) which are overlain uncomformably by the former constitutes the geanticlinal core of this group. These rocks, being strongly folded and frequently cut by thrust faults, are the oldest rocks in Central America. They are considered to be lower Palaeozoic in age by most of geologists today, though once believed to be Pre-Cambrian.

This group, affected with the regional metamorphism due to extensive granitic intrusions, consists of mica schists, chlorite schists, marbles, amphibolites and gneisses. Some of them contains considerably high grade metamorphic facies, such as biotite - garnet schist or kyanite-straurolite gneiss.

From the fact that the upper Palaeozoic Santa Rosa Group overlying these metamorphic rocks contain granitic pebbles at the base and that the age of granite has been proved to be 375 m.y. by the Sr/Rb method, the granitic rocks in this area are presumed to have already exposed on the surface when the upper Palaeozoic formation began to deposit.

These crop out a number of discontinuous serpentinite bodies along mayor fault systems like in the Northern Group. Attention is being paid to Ni-ore deposit accompanying these serpentinite bodies around Lake Izabel in the east of this area.

2-3. Southern Group

This is the area immediately south of Motagua fault system and includes Espiritu Santo mountain range running along the Honduras border. The degree of metamorphism in this area is generally low and the geology consists mainly of phyllite, metadiabase, chert, graywacke etc.

3. Volcanic Province and Guatemala - Quezaltenango Depression

Extensive volcanic activities have occurred in the sourthern Guatemala from the late Tertiary to Recent and the volcanic rocks intercalating the sedimentary rocks were laid mainly land, where the relatively flat Guatemala highland (Williams, 1960) with elevations of 1,000 ~ 2,000m have been produced. Some of Volcanoes on the southern periphery of this highland is still active today and a chain of more than 15 Quaternary volcanic cones having a height of 2,000 ~ 4,000m line up in south easterly parallel with the Pacific coast (Fig. III-3). This area is collectively called Volcanic Province.

The Volcanic Province extends trending southeast from the Mexican border to reache Costa Rica via El Salvador and Nicaragua. This extension is called the Pacific Volcanic Chain. This south-east trending volcanic chain crosses diagonally the east-west arc of the older Guatemalan Cordillera and runs almost in parallel to Middle American Trench having the maximum depth of 5,000 ~ 6,000m which lies approximately 100 km off the Pacific coast. Relationship between these structures will be given a further study in the future from a standpoint of gloval tectonics which has made remarkable progress in recent years.

In the continent, meanwhile, predominant depressions such as Central graben in El Salvador and Nicaragua depression (or graven), trending almost in parallel to this volcanic chain, have been confirmed. Also in Guatemala, the existence of Guatemala-Quezaltenango depression zone is presumed from Gravity Bouguer anormaly map of this area and the distribution of base rocks in Volcanic Province, as will be mentioned later (Fig. III-3).

The following is considered as the origin of this depression. In response to the Laramide orogeny in North America during the latest Cretaceous to early Tertiary, a regional compression occurred also in Central America along the Pacific coast about the same time, forming geanticline in the area of Pacific Volcanic Chain including Volcanic Province in Guatemala. The tension stress developed in the top of such geanticline created fissures of SE trending which later developed gradually into the present prominent fault system.

On the geology of Volcanic Province in Guatemala, Williams (1960) provides an excellent report in detail, which is served as a basis of geological studies in this area. However, the geology of this area is very complicated and efforts of many geologists over a long period of time will still be required for the clarification of volcanic stratigraphy which is an important problem for the future geothermal development. For convenience's sake, Williams divides volcanic rocks in this area into Tertiary volcanic rocks and Quaternary volcanic rocks, according to the physiographic differences. If the original constructional or depositional forms of volcanoes and their products are well preserved, rocks are considered as Quaternary volcanic rocks. If the original forms are eroded or dissected to a considerable extent, then the rocks are classified as Tertiary Volcanic rocks. The survey of the Zunil geothermal area on this occasion also used this classification without any substantial changes but no definite geological evidences sufficient for the determination of the age were available (Chapter VI).

3-1. Tertiary Volcanic Rocks

While Cretaceous volcanism in all Central American countries neighbouring Guatemala is well known, the oldest volcanism in Guatemala is presumed to have begun in Miocene on the basis of diatoms (Williams 1960) and continued until Recent. Volcanic rocks ranging from rhylites to olivine basalt are present in this province. Vast quantities of these lavas and pyroclastics formed complicated formation which are frequently intercalated such deposits as talus, landslide, mud flow, fluviatile, lake etc. and caused further complication of the stratigraphy of this area.

Tertiary volcanic rocks consist mainly of pyroxene andesitic lavas, tuff breccias and tuffs, intercalating rhyolitic tuff frequently or rhyoclastic flow deposits mixed with welded tuff at times. However, attention is focused on the sharp increase of rhyodacitic lavas and pyroclastic flow deposits toward the east of Guatemala. Of these Tertiary volcanic rocks distributed under underneath the geothermal area compact rocks are considered to be cap rocks while the permeable layers are served as geothermal reservoirs. However, the total thickness of the group as well as its stratigraphy are not definitely known even today. According the result of borings provided in the adjacent Atitlan Project area, the basement granite has been recognized at a depth of about 850 m (Electro-Watt Co. 1971). Therefore, the total thickness of this group is presumed to be over 1,000m.

One of the facts worthy of special attention about Tertiary volcanic rocks in Guatemala is that they do not show the slighest sign of submarine lavas, tuff or sea bottom sediment, which have been confirmed in south Central America and the Caribbean Sea, and that all Tertiary volcanic activities in Guatemala have been continental. This assumption is also supported by continental deposits of diatom, mud flow, gravels, and silt frequently intercalated in this group. This group is presumed to have buried deeply the Guatemala-Quezaltenango depression which had developed on the top of ascended geanticline.

Since Tertiary volcanic rocks show no signs of so-called quaquaversal flow structure, radial dikes, plugs and remnants of old cones, which are indicative of central eruption, most of the Tertiary volcanic activities are considered to have been fissure eruptions.

Following the latest Tertiary, these Tertiary rocks in this area gently folded and were then cut by many faults. These faults diagonally cross the NW-SE trending major fault systems predominant in the Pacific Volcanic Chain. N-S and NE-SW trending smaller faults are particularly notable. The fault bordering with the famous Guatemala City graben has N-S trending. The same trend was also confirmed in the area under survey. Attention is being paid to these findings since the faults and accompanying fractures provide a passage for geothermal fluid and the area around the crosspoint of a major fault and a sub-fault often becomes a predominant geothermal area.

3-2. Quaternary Volcanic Rocks

The Quaternary volcanic rocks are characterized mainly by pyroxene-hornblende andesites which form many volcanic cones. Further, many of these cones, during the last stage of their volcanic activities, erupted a vast amount of dacitic pyroclastic flow and other pyroclastics from their summit craters and some of them acidic andesites or more siliceous lavas from their flank sides with frequent formation of domes. In the southeastern section of Guatemala, however, andesites aften forme composite volcanoes, and also small basaltic cinder cones and lava flows.

These colossal Quaternary volcanic products, aften intercalating such continental deposits as gravel, sand and diatomaous earth, deposited almost horizontally to a considerable depth, thereby forming the vast Guatemala highland and are still being added even today with airfall ash and pumice.

Many of these Quaternary volcanoes stretching with NW-SE trending on the southern periphery of this highland form beautiful volcanic cones equivalent to Mt. Fuji in Japan. Of these volcanic cones, prominent ones are as follows from west to east. (Fig. III-3) : Volcan Tojumulco (4,210m), Volcan Santa

Maria (3,789m), with a world-famous volcanic dome of Santaguito (2,500m), Cerro Quemado (2,818m), Volcán Zunil (3,542m), Volcan Atitlan (3,537m), Volcán Toliman (3,158m), Volcan San Pedro (2,995m), twin volcanoes of Acatenango (3,976m) and Fuego (3,763m), Volcan de Agua (3,766m), Volcan de Pacaya (2,552m) Volcan Tecuamburro (1,945m), Volcan Moyuta (1,702m).

At the time of this survey, thick ash clouds were belching out from Fuego, and lava flows from Pacaya, which began six months previously, were still continuing though on a small scale. Santa Maria which is adjacent to the survey area in the west had tremendous explosions in 1902 and formed steepsided craggy Pelean dome, named Santaguito, on its south flank later in 1922. The dome had grown about 400m in hight a year later. Even today, the dome is still rising and expanding. This dome resembles closely to Showasinzan (406m) in Japan which began its activities in 1943.

There is a chain of beautiful calderal lakes or caldera-like lakes between the rows of these volcanoes. In the area including Volcan Atitlan, Volcan Toliman and Volcan Pedoro, each of which forms a volcanic cone, there is Lake Atitlan with an area almost equivalent to that of Aso Caldera in Japan, the largest caldera in the world, boasting its spectacular view together with Lake Amatitlan located at the north base of Volcan Pacaya southwest of Guatemala city. These two lakes were formed by cauldron depression or volcano-tectonic depression. Lake Ayarza (approximately 2,000m in elevation) in the north of Volcan Moyuta is said to be a caldera lake (Williams 1960).

3-3. Guatemala-Quezaltenango Depression

Basement rocks of Volcanic Province, occurred as the scattering inliers (so-called fenster) of various sizes, consist of granites slightly altered pelitic sediments and limestones. Of these, black shales and phyllites probably correspond to upper Paleozoic formation (Pennsylvanian-Permiam) distributed in the Central Cordillera immediately adjacent to this Province to the north. The age of the limestones has been determined to be Albian (uppermost lower Cretaceous) based on large-sized Foraminiferas obtained near Guatemala city (Williams 1960) and is correlated with the Cretaceous carbonate of Coban formation.

Judging from the distribution of these a large part of basement rocks in this Province are presumed to comrise mainly granitic rocks. They were determined to be Cretaceous (92 - 99.7 m.y.) in age by radiometric dating of biotite granite and diorite obtained wear Guatemala city (Williams 1960). However, the Paleozoic plutons distributed in the Central Cordillera to the north of this area are recognized as previously mentioned, and also the intrusion of granitic rocks associated with younger Tertiary volcanic activities has been presumed. Accordingly, Tertiary and Palaeo, granitic rocks may also be existed in the substratum of this Province.

Fig. III-3 was prepared from a combination of the distribution of these mostly Pre-Tertiary basements and Bouguer anormaly map of Guatemala (Instituto Geografico Nacional, Guatemala, 1965). As is evident from the chart, there distributed a low gravity anormaly zone (at least - 100 ~ 150 mgal. D=2.67) of NW-SE trending in the north of a row of Quaternary volcanic cones in parallel to it. This low gravity anormaly has a width of about 10 km and a length of about 300 km. Since its distribution coincides with the line drawn between Guatemala city and Quezaltenango city, it is called the Guatemala-Quezaltenango depression.

Pre-Tertiary basement rocks, most of which show inliers, are distributed on the north and south sides of this depression zone. It is apparent from this fact that this tectonic line obviously suggests the depression of the basements and that the activities of the row of Quaternary volcanic cones were located along the southern margine of this depression. This theory is in consistent with the fact that a row of Quaternary volcanic cones is arranged mainly on the south side of the central graben of El Salvador which is considered to be the southeastern extension of this depression.

However, this Bouguer anormaly map may be only a summary of findings of a preliminary survey in Guatemala on the whole. Therefore, the previously mentioned north-south trending fault system and associated Guatemala city graven, as well as cauldron depression or caldera lakes such as Atitlan, Amatitlan and Ayarza and others, will require a more detailed survey and investigation in the future.

Geothermal provinces characterized by such gravens or depressions associated with post Cenozoic orogenic zones and volcanic zones are found in many parts of the world. Geothermal provinces almost equivalent ot Guatemala-Quezaltenango depression in scale (Yamasaki 1972, Kubotera 1965, Ishita 1972) are (1) Aso-Beppu depression of Japan, including Otake geothermal area (30 ~ 40 km in width and more than 100 km in length), (2) White Island-Taupo depression (about 30 km in width and more than 200 km in length) which constitutes the New Zealand geothermal area and (3) a geothermal area in the Kamchatka Peninsula in USSR. The huge graben that includes grand scale Salton Sea geothermal area (USA) and Mexicali geothermal area, extending beyound the US-Mexican border, are exactly under the same category except for the difference in scale. It is interesting to note that all of these grabens, together with those in Central America, are distributed in the same Circum Pacific Volcanic and

Orogenic zone. Characteristics common to these grabens may be summarized as follows.

(1) Grabens or depressions are filled with post Tertiary and the younger sediments. These sediments may be weakly indurated gravels at times and often intercalate tuffaceous rocks and lavas. In general, permeable tuff, tuff breccia and gravels among these sediments form a geothermal reservoir, while compact clayey rocks, welded tuff and lavas form a cap rock. Thus, as to the reservoir, attension be paid to the foundary of two different rocks or formations from the viewpoint of permeability.

(2) While grabens and depressions involve many volcanic bodies, many geothermal areas in these grabens and depressions are frequently associated with caldera, volcanic dome lava dome etc. The caldera is an area which has depressed further within the depression area as a result of with draw of mayma due to volcanic eruptions. Since the caldera is accompanied by many faults and fractures which allow the rise of geothermal fluid, it provides favorable conditions as a geothermal area. Volcanic domes and lava domes are formed by the intrusion of highly viscous lava as evidenced by the previously mentioned Showa-Shinzan (Japan), Santiguito and Cerro Quemado (Guatemala). Under the influence of the introsion, the radial, circular or irregular faults and fractures develop around the intrusive body to provide the geothermal passages.

(3) The younger faults that cut through sediments filling up grabens or depressions have developed in many instances. This means that these areas are unstable where crustal movement had continued until very recently. The so-called "active faults" are also observed in sometimes. These faults often develop in parallel to the major faults bordering on both sides of the graven or crossing these major faults diagonally. Importance is attached to the area flanked by dominant faults or the area near the crosspoint of faults as an area rich in geothermal fluid. In short, fracture zones associated with faulting are also important as the geothermal passages or reservoirs.

(4) With the increasing accuracy of survey techniques in recent years, more hopes are now placed on local and minor anticlinal areas within the graben or depression. This expectation is similar to that entertained for petroleum deposits that are found on the top of anticline.

4. Pacific Coastal Plain

In the south of Volcanic Province, the steep slope of Quatenary volcanic chain suddenly develops into a Pacific coastal plain, approximately 50 km in width, An enormous amount of detritus produced as a result of mudflows, land-slide or torrential flood from the Volcanic Highland, has been constantly supplied to this plain with talus and alluvial fans developing extensively on the slope. Accordingly, sediments in this area comprise rhyolites and basalts at times, andesites boulders, gravels, sand and clay in most cases and airbone ash and pumice frequently, showing remarkable diversification in seraligraphy.

5. Outline of Geologic History of Guatemala

In order to realize the geologic outline of Guatemala, the geologic history of this country will be touched on briefly as summarized in Fig. III-4. Because of the lack of sufficient data, the summary shown is far from complete and may require correction in many respects in the future.

(1) The geologic history of Guatemala may be divided largely into the following two geotectonic cycles, as suggested in Mexico: Taliscoan geotectonic cycle during a period from lower Palaeozoic to Permian and Mexican geotectonic cycle in the subsequent period.

(2) Taliscoan geotectonic cycle begins with the deposition of lower Paleozoic formation (Chuacus formation) distibuted in Central Cordillera, the oldest formation in Guatemala. Then the orthogeosyncline epicontinental sea receiving the sediments is believed to have extended from Mexico, Guatemala and northern Honduras widely into the present Caribbean Sea, while the foreland (Continent) is presumed to have been situated in the present Yucatan platform. The area of this orthogeosycline after the depositions was affected by regional metamorphism due to strong folding and intrusions of granitic rocks. The basal part of upper Palaeozoic formation (Pennsylvanian-Permian) which uncomformably overlain the metamorphic complex and granitic rocks, thus formed, apparently contains granitic pebbles. Therefore the granitic rocks had already exposed on the ground surface at the beginning of the deposition of the upper Palaeozoic formation and the time of their intrusion is apparently older than upper Palaeozoic (Dating revealed the age to be 375 m. y.).

(3) The subsequent orthogeosyclines receiving the sediments of upper Pallaeozoic formation (Clastic Santa Rosa group and carbonates chochal formation) turned into a land caused by the renewed folding of the Jaliscon orogeny during a period from late Permian to Triassic. For this reason, no

Triassic sediments are found in Guatemala.

Many fault systems trending E-W arc, as already mentioned, developed in parallel to the axis of geanticline due to the Jaliscon orogeny during this period. These fault systems are believed to have developed later into the previously mentioned major faults such as Polchic and Motagua under the influence of Laramide orogeny of U. S. A. which began in the latest Cretaceous. On the other hand, these E-W trending fault systems are presumed to have extended to the Caribbean Sea and have also close relations with the origin of Barttlet trough (of the sea) (taphrogenetic movement). These fault systems are also considered to have accelerated intrusion of serpentinite now distributed along the E-W trending fault system.

(4) In the basin-like area which turned into land following the Jaliscon orogeny, there distributed locally thick deposit of continental molassic red beds (Todos Santos formation), indicating the end of Jaliscon geotectonic cycle.

(5) The subsequent Mexican geotectonic cycle began with the deposition of clastic rocks and carbonates (coban, Ixcoy, etc) in geosycline from latest gurrasic to Cretaceous. This geosycline again became the stage of the subequent major orogeny starting from the latest Cretaceous.

(6) The orogeny during the latest Cretaceous to lower Tertiary (Eocene) corresponds to Laramide orogeny in USA. In Guatemala, extensive intrusions of granitic rocks (Cretaceous-Tertiary, refer to Chapter III, 3-3) and folding are presumed to have taken place mainly in the Central Cordillera area and Volcanic Province in the south, while the E-W trending fault systems such as Polochic and Motagua and the Bartllet trough are considered to have been nearly completed in this stage.

Meanwhile, the previously mentioned serpentinites are presumed to have been exposed on the ground surface in this stage for the first time. The reason for this assumption is that the deposits formed prior to this orogeny show no traces of serpentinite pebbles which are found in large quantities in the basal part of super formation of the subsequent ages.

(7) About the same period of the orogeny mentioned in the preceding paragraph, almost all parts of Guatemala turned to a continent with only exception of southern part of Peten Lowland where depositions of marine flysh clastic Sepur formation are observed. Especially in the period of upper Paleogene (early Eocene-Oligocene), nearly the Guatemala is considered to have occurred extensive peneplation. Since then, most of the northern part of this country including Peten Lowland has seen continuous deposition of the

younger Tertiary continental and evaporate rocks.

(8) About the same period of these orogenic movements or in the subsequent period, the Pacific volcanic chain in Central America with NW-SE trending including Volcanic Province in Guatemala was affected by a regional compression. The previously mentioned Guatemala-Quazaltango depression, Central graben in El Salvador and Nicaragua depression with NW-SE trending are presumed to have developed on the top of geanticlinal axis formed by this regional compression in parallel to the axis. These depressions were then filled with volcanic rocks of younger neogene Tertiary (Miocene), and later occurred block movements mainly of N-S trending as represented by Guatemala city depression. The Quatermary volcanic chain which has been still very active to the present is distributed along the southern periphery of this Volcanic Province.

In conclusion, such a geotectonic and volcanic history of volcanic province may be said to account for the geologic background of all geothermal provinces with SE trending in Central American countires.

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Fig. III-1. Physiographic Provinces of Guatemala
(After S. Bonis 1967, partly modified)

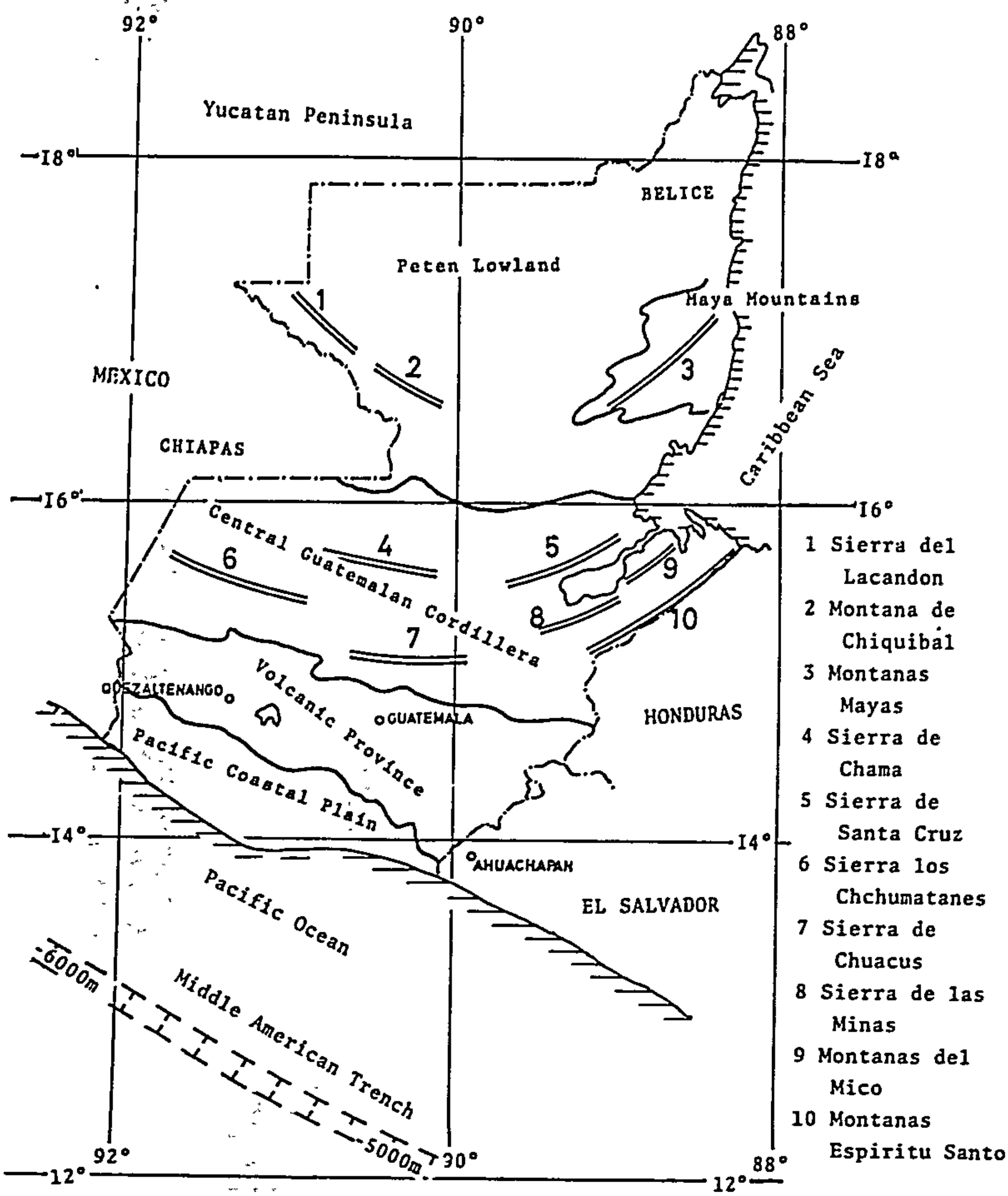


Fig . III-2. Geologic Map of Guatemala
(Compiled by YAMASAKI and MATSUMOTO 1973, from Geologic Map of Guatemala 1/500,000)

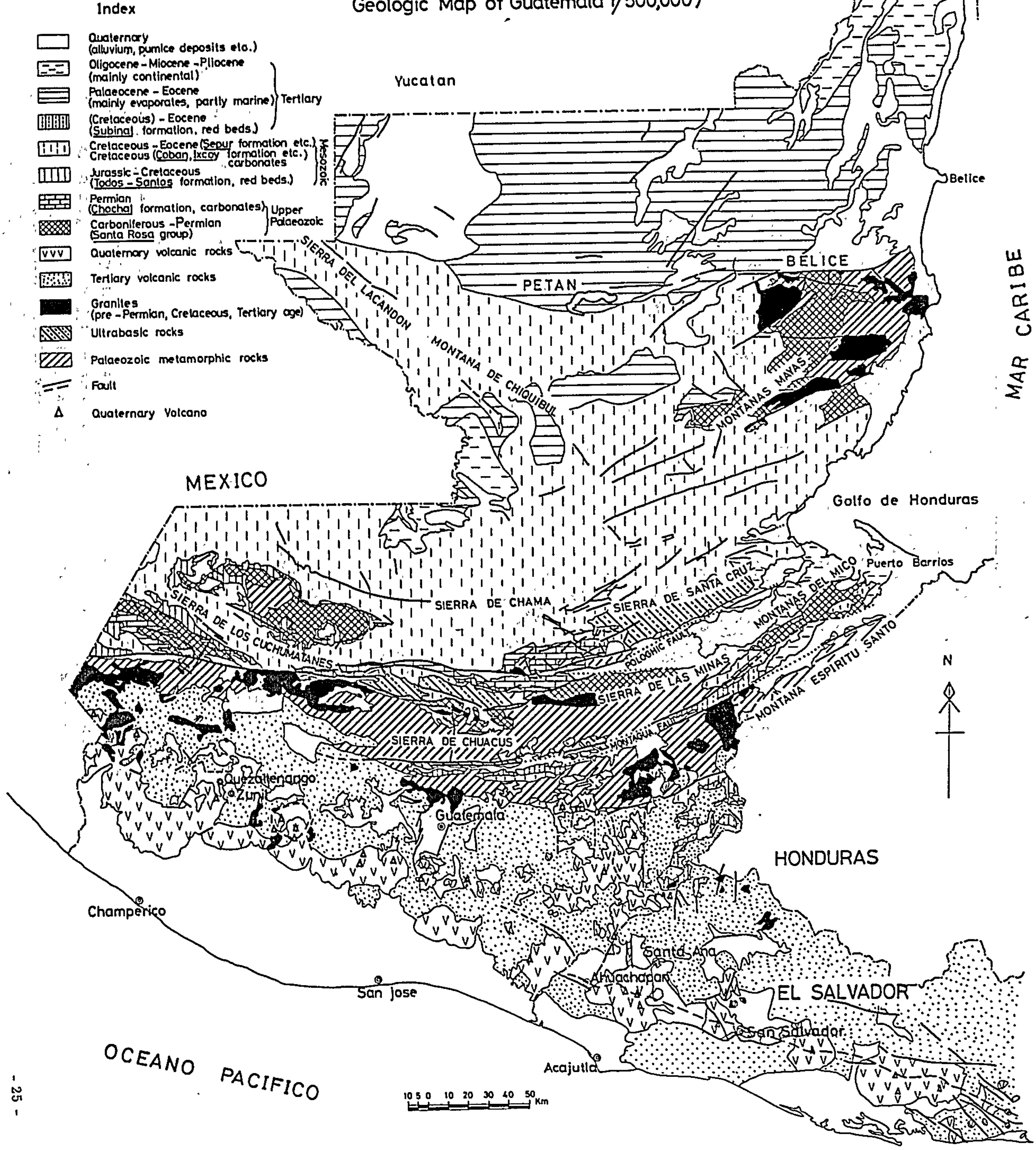
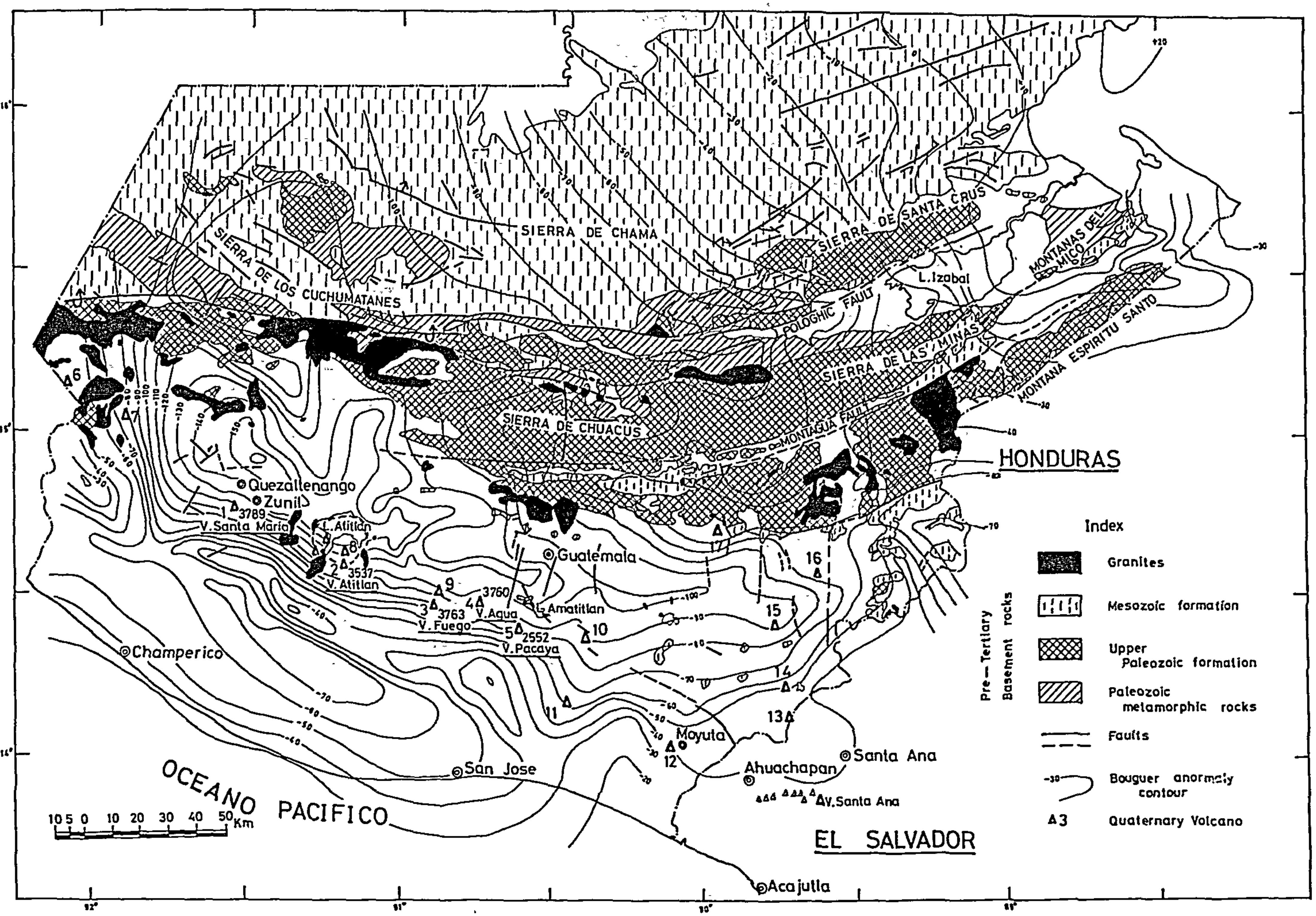
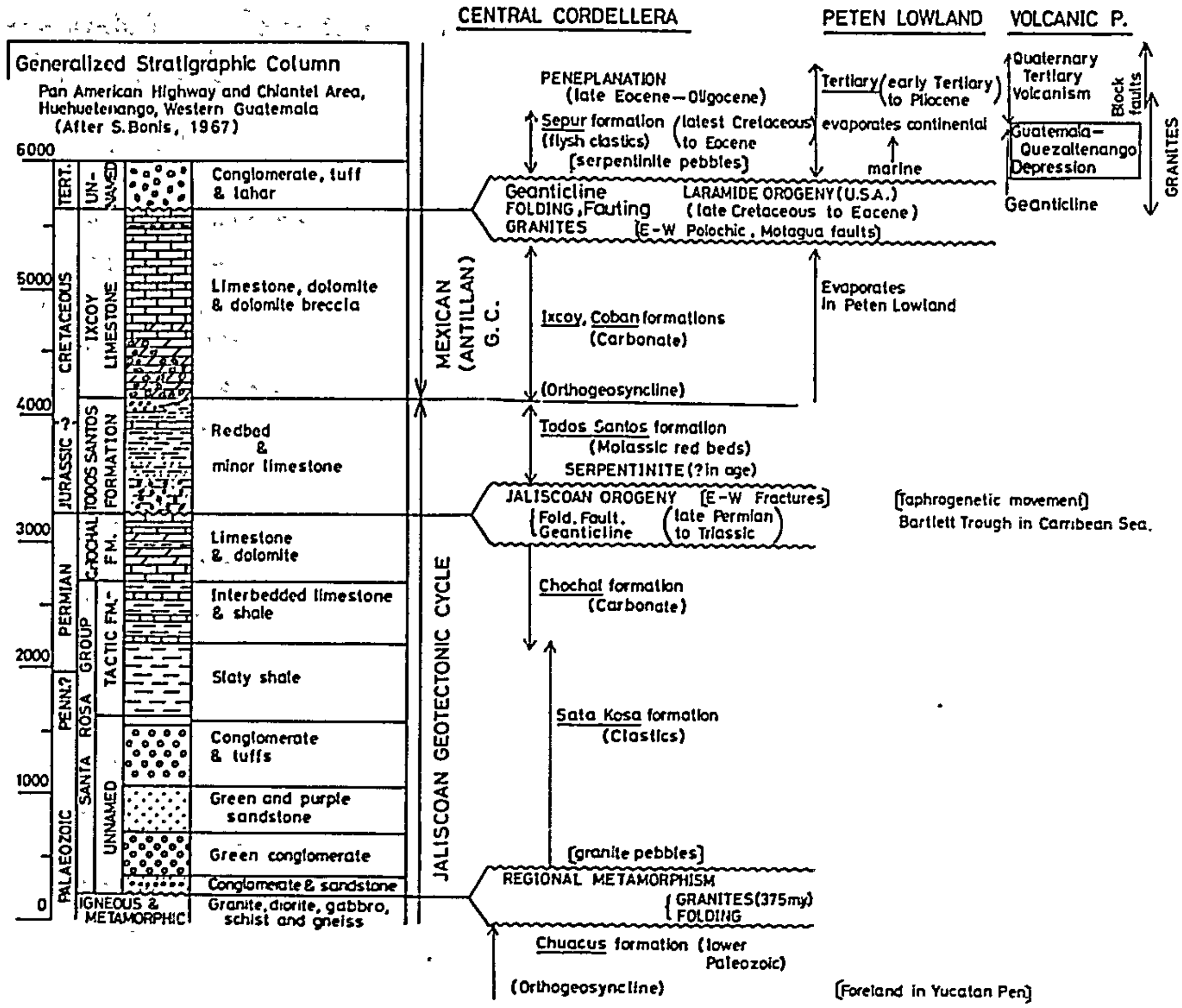


Fig. III-3. Relation between Bouguer Anomaly (unit mgal) and Pre-Tertiary Basement Rocks, Guatemala
(YAMASAKI and MATSUMOTO, 1973)



1. V. Santa Maria (3790)	2. V. Atitlan (3537)	3. V. Fuego (3763)	4. V. Agua (3760)	5. V. Pacaya (2552)
6. V. Tacana	7. V. Tajumulco (4210)	8. V. Toliman (3158)	9. V. Acatenango (3976)	10. C. Redondo (1077)
11. V. Tecuamburro (1945)	12. V. Moyuta (1702)	13. V. Chingo (1775)	14. C. Las Viboras (935)	15. V. Suchitan (2006)
16. V. Ipala (1650)	17. V. Jumay (2180)			

Fig. III-4. Outline of Geologic History, Guatemala (YAMASAKI, 1973)



CHAPTER IV GEOLOGY OF THE ZUNIL GEOTHERMAL AREA

There develop the country's most active geothermal manifestations, including Fumarole Grande on the bottom of the deep valley of the Samala River and Fumarole Negra to the east, on the south of Zunil Village located approximately 8 km to the south-east of Quezaltenango City. The area covers 1 ~ 2 km^2 and there are active fumaroles, solfataras, hot springs and marked altered zones as well as the geyser of Fumarol Grande with large discharge in this area, and it is one of the most promising areas for geothermal development. And further, there are scattered more hot springs, fumaroles and altered zones in the surrounding areas (Fig. IV-1). This area is tentatively termed the "Zunil Geothermal Area", and this name will have to be reconsidered after the nature, scale and scope are defined as a result of further investigations in the future.

The Zunil Geothermal Area is located in the south-western part of the aforenamed Guatemala-Quezaltenango Depression (III-3) running NW-SE in the Volcanic Province in Guatemala and on the south border of the so-called Quezaltenango Basin showing maximum -160 mgal of negative Bouguer anomaly. On the west side of the area are still active volcanos, namely Cerro Quemado (3,197 m) which is a gigantic volcanic lava dome, Santa Maria (3,789 m) which is a beautiful conical stratovolcano, and Santaguito Dome (2,500 m ±), etc., and on the southeast side there are the complex volcanic zone ranging from Zunil Volcano (3,542 m) to Santo Tomas Volcano (3,505 m) close by. And the Samala River flows from north to south through nearly the center of this Zunil Geothermal Area surrounded by these volcanos.

1. Volcanic Stratigraphy

1-1. Outline

The geologic succession of the Zunil Geothermal Area is classified roughly into two, namely one is the Zunil Group (Neogene Tertiary volcanic rocks) covering the basement granitic rocks, and the other is the Cerro Quemado Group (Quaternary volcanic rocks) intruding into or covering those rocks. As stated in III-3, this classification terms the succession in which the original forms of volcanic bodies and volcanic products are preserved well "Quaternary" and terms the other "Tertiary" according to Williams (1960) and the exact geological chronologic classification is still left as the subject of future study.

These are subdivided further as shown on Table IV-1, by which the geologic sketch map shown on Fig. IV-1 was prepared.

The subdivision like this of the Tertiary volcanic rocks is probably the fist trial in this country. However, since this is based on the results of only 10 days' reconnaisance, it will be revised and improved by the detailed geological surveys, test borings and other studies in the future. These 2 groups are directly related with the formation of the geothermal area in this district and further stratigraphic study is needed for clalification of the characteristics of the reservoirs and cap rocks.

For this purpose, thin sections prepared from approximately 100 samples collected in the present survey, were studied in more details by microscopic observation as the bases of future studies. The typical examples are included in the report.

(1) The basement granitic rocks do not outcrop in the Zunil Geological Area directly. However, they crop out in large and small inliers at Cajola and Totonicapan to the north and near Lake Alitlan to the east of this area, and also glanitic rocks were confirmed by the test borings at the Atiltan Project. It is presumed from the above, that granitic rocks are distributed widely under the ground as the basement rocks of the Zunil Geothermal Area.

(2) The Zunil group belongs to the Tertiary volcanic rocks according to Williams (1960) and Bonis (1965). These are mostly supposed to be due to the Neogene Tertiary volcanic activities and they are presumed to correspond to the green tuff activities in Japan, but further study must be made to determine the accurate age. These are distributed widely in the basin and the left bank of the Samala River, and the Zunil Group divided in 4 formations crops out in the order of lower to upper layers from the downstream part to the upstream part.

(3) The Cerro Quemado Group consists of many large and small lava dome volcanos and stratovolcanos intruding into or covering the Zunil Group, and the Cantel formation which presumably consists mainly of lucustrine sediments, etc. These are all supposed to be due to the Quarternary volcanic activities. Since a geothermal source is expected at the deep underground part under Cerro Quemado which was active until recently, it is necessary to clarify in detail the volcanic history of this group.

(4) Alluvial deposits form the alluvial plains in Almolonga and Zunil basins and the ground surface near Cantel and Pasac.

(5) The major topographical features of this area are summarized as follows.

Quezaltenango City is situated nearly at the center of the basin-like topography. This basin-like topography ranges about 23 km east-west and 5 ~ 10 km north-south, and has an elevation of 2,300 ~ 2,400 m. This basin-like topography is supposed to be due to volcano-tectonic depression, but it is yet to be clarified by future studies. This basin-like topography was once a lake, when the lake deposits, Cantel formation, were formed by the supply of volcanic products from the surrounding areas.

There are mountains of 3,000 m class to the north of this Quezaltenango Basin, and their south sides form steep dliffs, which are supposed to be fault scarps. There are many volcanos in a range to the south of Quezaltenango, for instance, the gigantic lava dome Volcan Cerro Quemado (3,197 m), the Zunil Volcanic Area (3,542 m) with a lava dome as the main peak, Santa Maria (3,772m) which is supposed to be a stratovolcano, and many associated volcanos.

The Samala River collects the water from the Quezaltenango Basin and flows south-southwest from Cristobal and Totonicapan on the north, joins the Xequijel River on the east of Quexaltenango City, flows southeast to Cantel, and flows nearly southwest from there. Along the course of this river, there are hot springs and the Zunil Falls downstream, which are falls on the very recent lava flow from the middle of Volcan Cerro Quemado. There are conspicuous geothermal activity areas downstream of the falls, which form a steep V-shaped valley.

1-2. Details

1-2-1. Basement Rocks

The basement rocks do not crop out directly to the surface in the Zunil Geothermal Area, but they crop out, in inliers of various sizes surrounded mainly by the Tertiary volcanic rocks, at Cajola about 10 km to the northwest of Quezatlenango City, at Totonicapan about 12 km to the northeast of the City, around Lake Atitlan and the Nahualate River Basin about 25 km to the east-southeast of the Zunil Geothermal Area. These are biotite-granite, biotite -hornblende-granodiorities, etc.

Granitic rocks were also confirmed as the basement rocks by the test borings in the Atitlan Hydro Power Project. The test boring at 3 km east-southeast of Cantel (Fig. IV-1, Sondeo-Drilling, Jolom 1, El. 2,610 m) reached the basement granities at 250 m depth (core is lacking for 235 ~ 250 m depths), which means that the granites exist at El. 2,360 m. The test boring at about 8 km east-southeast of Cantel (Sondeo-Drilling No. 7, El. 2,526.5 m) reached the basement hornblende-biotite and granodiorite at the depth of 320 m, or at El. 2,206.5 m. The center part of the Zunil Geothermal Area, where there is no outcrop of granites, is at El. 1,800 ~ 2,000 m, and therefore it is supposed that the granities lie still deeper in this area. It is supposed that the granites lying to the northeast and east of this area drop in step faults towards the volcanic area including Quemado and Santa Maria on the west. However, the depths are yet to be clarified.

In the pyroclastic rocks of the Zunil Group are frequently found biotite-granites and biotite-hornblende granodiorites mixed as a accidental materials. Especially, many granitic breccias of the basement rocks are mixed in the Lowest formation. According to Williams (1960), biotite-granite, hornblende-quartz diorite, hornblende-biotite-quartz monzonite, etc. were confirmed as accidental objects at the time of volcanic activities of Santa Maria in 1902. On the other hand, granit porphyry, quartz porphyry, etc. as well as the above-named granitic rocks are formed-as foreign matters in the volcanic rocks in this area, and frequently as gravels in the Recent river bed gravel layers of the Samala River.

Judging from the foregoing, though no outcrop of granitic rocks and granite porphyry can be found on the surface in the Zunil Geothermal Area, it is presumed that they are distributed widely under the ground.

The geological age of these basement rocks are believed to be Cretaceous (Williams, 1960), and the age determination by the K-Ar method by Evernden shows 92 m.g. The most part of the basement granitic rocks in this area are of the Cretaceous age. However, there remains the possibility of occurrence of the Paleozoic to Tertiary granites distributed in the above-mentioned northern Guatemalan Cordillera, or Paleozoic to Mesozoic formations.

These basement granitic rocks are covered by the Zunil Group in unconformity relations, and this unconformity surface must be noted as one of the geothermal reservoirs. Its depth is very important for the determination of distribution and thickness of the Zunil Group which is considered to be an important geothermal reservoir in this area. This is one big item of the future surveys.

1-2-2. Zunil Group

The Zunil Group is distributed generally towards north along the Samala River, from La Estanicade le Cruz through Zunil to the south of Cantel, from the lower to the upper layers. This group which used to be called collectively "Tertiary volcanic rocks" in this country (Williams 1960, Bonis 1965, etc.) will be named the

"Zunil Group" in this area now. This is an important geologic system forming reservoirs and cap rocks under the ground of the Zunil Geothermal Area.

This Zunil Group is divided into 4 formations, namely 1 the Lowest formation mainly consisting of tuff breccias of pyroxene andesite, 2 the Lower formation mainly consisting of pyroclastic flow deposits, 3 the Middle formation mainly consisting of pyroxene andesite lava and tuff breccia of pyroxene andesite, and partly including hornblende andesite lava, and 4 the Upper formation consisting of pyroclastic flow deposits and tuff breccia. Unconformity was confirmed between the Lowest formation and the Lower formation, but unconformity has not been observed yet between the upper formations.

(1) Lowest Formation

The Lowest formation is distributed only in a very limited area near Fumarole Negra located on the downstream of the Pachamiya River, a tributary of the Samala River. Here, a nearly flat outcrop of tuff breccia of basaltic an desite is seen, and the confirmed thickness is about 20 m at the maximum, the lower limit being yet to be found out. A considerably undulating erosion surface is observed on the top of this layer, and it is completely covered by the fairly thick pumice flow deposits of the Lower formation of the Zunil Group.

These two formations are intruded by the dome-shaped intrusive body (approximately 200 ~ 300 m in diameter) of rhyodacite included in the Cerro la Pedrera lava to be described later, on the west side of Fumarole Negra. This dome is accompanied by intrusion breccia on its periphery, and the contact surface between rhyodacite and Tertiary formations shows approximately N25°W and W25° and shows the occurrence of intrusion from the underground lower part towards the east upper part. Small faults cutting the ryodacite dome are observed and the fault plane shows N53°E and NW65°. These are associated with the fault in NE-SW direction running from Cantel through Zunil Village to La Estanica de la Cruz which will be described later, and probably the rhyodacite intruded along such faults.

The west side of this rhyodacite dome makes a precipice on the left bank of the Samala River in the V-shaped valley, and at the foot near the river bottom there is a dominant geyser called Fumarole Grande. Thus, the area's two most dominant geothermal manifestations of Fumarole Grande and Fumarole Negra have been confirmed on both sides of and adjacent to this dome. This is considered to be due to the fact that there developed remarkable cracks around and due to the intrusion of highly viscous ryodacite, forming good passages for the geothermal fluids.

The Lowest formation includes breccias of basaltic andesite as the essential material and breccias of granitic rocks, granite porphyry, quartz porphyry, etc. of the basement rocks due to the activities in the Cretaceous period, are observed as accidental materials. These breccias are generally of diameters of several centimenters to 10 cm, but some measure 30 ~ 40 cm at the maximum.

(Description of Rock)

The essential breccia of the tuff breccia forming the Lowest formation, is the basaltic andesite and the description of rock is as follows.

Specimen No.:	No. 73031210
Name of Rock :	Olivine-hypersthene-augite basaltic andesite
Place of Sampling :	Fumarole Negra downstream of the Pachamiya

This is a porphyristic rock with relatively small phenocrysts. The fresh part is a compact rock of grayish black color, but it frequently shows gray to grayish brown color due to alteration and/or weathering.

The phenocrysts consist of olivine, hypersthene, augite, magnetite and plagioclase, but the quantity is not too great. The olivine exists as microphenocrists of 0.5 mm or less, but is all altered and replaced with serpentine and calcite, with the reaction rim of pyroxene granules on the periphery. The hypersthene is observed as small phenocryst of 0.5 mm or less and the augite of 0.8 mm or less. The magnetite is observed generally as micropenocryst of 0.2 ~ 0.1 mm. The plagioclase is of column-shape of 1.5 mm or less and is labradorite ~ andesine. The ground mass shows intersertal ~ intergranular texture and consists of minute strip-shaped plagioclase, pyroxene granules, magnetite, ilmenite, crystallite, etc.

(2) Lower Formation

The Lower formation is distributed mainly on the left bank of the Samala River, and as shown in Fig. IV-1, Geologic Map, is often cut by faults and forms relatively low flat hills. As stated before, this formation covers the erosion surface of the Lowest formation, and these two formations show a distinct unconformity relationship. The thickness is considered to be at least

70 m and reach 200 m at the maximum.

The lowest part of this formation has partial parting of dacitic tuff breccia, but most of the upper part consists of rhyolitic pumice flow deposits, which is considered to be mostly continental deposits. At least 2 sheets of pumice flow units have been confirmed, and there are several layers of air-fall pyroclastics and air-fall scoria of 20 ~ several cm thickness in between, and the total thickness is about 2m.

The pumice as the essential material of this pumice flow deposit has a diameter of 3 ~ 1 cm, several centimeters at the maximum, and is of not too good vesicle formation. The matrix is pumiceous lapillic ~ pumiceous ash and is nonwelding. The pumice flow deposits include the basement rocks and andesites as accidental materials.

(Description of Rock)

The description of the pumice as the essential material of the pyroclastic flow deposits forming the Lower formation is as follows.

Specimen No. :	Nos. 73031212, 73031606, and 73031607
Name of Rock :	Hornblende-biotite-rhyolitic pumice
Place of Sampling :	Right bank near the fumarole downstream of the Pachamiya, and left bank on the downstream

The white porous vitreous base is spotted with dark minerals of biotite and hornblende.

It includes hornblende, biotite, magnetite, quartz and plagioclase as phenocrysts and microhenocrysts, and the quantity of phenocryst is small. The hornblende is 0.5 mm in size at the maximum and mostly is hypidiomorphic and of green color. The biotite is smaller than 0.7 mm and is often inflected. The magnetite is observed as microphenocrysts smaller than 0.1 mm. The quartz is 1 mm or smaller. The plagioclase is of long column shape ~ short column shape of 0.1 mm or less, and mostly andesine. The groundmass is vitreous and includes small quantities of hornblende, biotite and crystallite.

(3) Middle Formation

The Middle formation is distributed in the area ranging from the northeast slope of Galapago Volcano to both banks of the Samala River, at the small inlier near Amargas Hot Spring in Balneario Aguas on the left bank of the Samala, on the relatively high slope ranging from the east of Fuentes Georginas Hot Spring on the upstream to the southeast of Zunil, and on both banks of the Samala south-south-southeast of Cantel.

The Middle formation is composed of the alternation of lava and tuff breccia, mainly of pyroxene andesite lava and tuff breccia with subsidiary hornblende andesitic rock and tuff breccia. The thickness of a layer is approximately 20 m generally, with occasional layers of 30 m. This formation has occasional parting of tuff and lapillic tuff, a part of which is subaqueous deposit layers. These have general thicknesses of several meters. The total thickness of the Middle formation exceeds 250 m and is supposed to be more than 300 m at the maximum. The hard lavas often form steep clifts, and good outcrops are observed on the right bank of the Samala River to the south of Cantel and on the right bank of the Pachamiya River. The latter is the alternation of 3 layers of laver flow of 20 ~ 30 m thicknesses and tuff breccia, and here the top lava is olivine-augite basaltic andesite and the 2 lower layers are two pyroxene andesite. The lava has conspicuously developed columnar joints accompanied by platy joints and fissures, and it serves as the passage of geothermal fluids and it is sometimes expected to make reservoirs.

This formation has various rock types such as olivine-augite basaltic andesite, olivine bearing hypersthene-augite andesite, two pyroxene andesite, olivine bearing two pyroxene-hornblende andesite, augite-hypersthene-hornblende andesite and hornblende andesite.

(Description of Rock)

Various rock types are observed as stated above, and the description of each rock type is as follows.

Specimen No. :	Nos. 73031701, and 73031804
Name of Rock :	Olivine-augite basaltic andesite
Place of Sampling :	Balneario Fuentes Georginas Hot Spring and El. 2,420 m point on the right bank of the Pachamiya to the south of Zunil.

Note : No. 73031701 is the essential breccia of tuff breccia from Balneario Fuentes Georginas Hot Spring, and No. 73031804 is the lava from El. 2,420 m point on the right bank of the Pachamiya.

This is a black ~ grayish black hard compact rock with phenocrysts of 1.5 mm or smaller.

The phenocrysts are olivine, augite and plagioclase. The olivine is smaller than 1 mm and has reaction rim of pyroxene granules on the periphery. The augite is of short column-shape and is idiomorphic ~ hypidiomorphic. The magnetite is smaller than 0.2 mm. The plagioclase is smaller than 1.5 mm and idiomorphic ~ hypidiomorfic, and is mainly labradorite. The groundmass shows intersertal texture and is composed of minute strip-shaped plagioclase, hypersthene, augite, magnetite, ilmenite, crystallite and glass.

Specimen No.:	Nos. 73031604, and 73031904
Name of Rock :	Olivine bearing two pyroxene andesite
Place of Sampling :	Left bank of the Samala downstream of Fumarole Grande, and left bank of the Samala about 2,000 m south-southeast of Cantel

This is a grayish black compact hard porphyristic rock with phenocrysts of 2 mm or smaller.

The phenocrysts are olivine, hypersthene, augite magnetite, plagioclase and rarely biotite as xenocryst. The olivine is observed as corroded micro-phenocryst of 0.3 mm or smaller, and it is in many cases altered and replaced with serpentine and calcite. The hypersthene is in idomorphic crystal of long column shape ~ short column shape of 0.7 mm or less. The augite is of short column shape of 1 mm or less. The magnetite is micropheno-crysts of 0.2 mm or smaller. The plagioclase is generally 1.5 ~ 1 mm size, 2 mm at the maximum, and is labradorite ~ andesine. Holocrystalline rocks consisting of seemingly cognate inclusion of hornblende, augite and plagioclase are also observed. The groundmass shows intersertal ~ hyalopilistic texture, and is composed of plagioclase, pyroxene granules, magnetite, crystallite, glass and clay minerals.

Specimun No. :	Nos. 72031301, 72031510, 72031601, 72031605, 72031801, 72031802, 72031803, 72031805, and 72032006
Name of Rock :	Two pyroxene andesite
Place of Sampling :	Various locations on both banks of the Samala

This is a gray ~ grayish black compact and hard rock, and is generally porphyristic rock with phenocrysts of 2 mm or less, but the size of the phenocrysts differs by the area and by the lava flow, and in some cases the phenocrysts are smaller than 1 mm and are not conspicuous.

The phenocrysts consist of hypersthene, augite, magnetite, plagioclase, etc. The hypersthene is smaller than 1 mm and in some rocks it is smaller than 0.3 mm. The augite is generally smaller than 1 mm, but in some rocks it is as large as 2 mm or smaller than 0.5 mm. The magnetite is smaller than 0.2 mm. The plagioclase is smaller than 2 ~ 1.5 mm and is labradorite andesine. The groundmass shows intersertal ~ hyalopilistic texture, and is composed of strip-shaped plagioclase, hypersthene, augite, crystallite, glass, iron minerals and clay minerals.

Specimen No. :	Nos. 73031207, and 73031905
Name of Rock :	Olivine bearing two pyroxene andesite
Place o Sampling :	Both banks of the Samala, about 2,000m south southeast of Zunil

This is a grayish brown ~ grayish black colored, relatively coarse-grained rock, and is porphyristic rock with phenocrysts of 2 mm or smaller.

The phenocrysts consist of olivine, augite, hypersthene, hornblende, magnetite and plagioclase. The olivine is smaller than 0.8 mm and shows corroded form and has the reaction rim of pyroxene granules. The hypersthene is smaller than 1 mm, the augite is smaller than 0.5 mm and they show idiomorphic ~ hypidiomorphic short columnar shape. The hornblende is smaller than 2 mm and idiomorphic ~ hypidiomorphic, and is brown hornblende with opasite rim. The magnetite is microphenocrysts of 0.2 mm or less. The plagioclase is generally smaller than 2 mm, but is sometimes 2 mm, and is labradorite ~ andesine. The groundmass shows intersertal texture and is composed of strip-shaped plagioclase, hypersthene, augite, magnetite, hornblende, crystallite, glass, etc.

Specimen No. :	Nos. 73031101, 73031208, 73031906, 73031910, 73031912 and 73031913
Name of Rock :	Two pyroxene hornblende andesite
Place of Sampling :	Both banks of the Samala about 1,600 m south of Cantel

This is a grayish-brown colored somewhat coarse grained rock, and is a porphyristic rock spotted with phenocrysts of 3 mm at the maximum.

The phenocrysts are hornblende, magnetite and plagioclase, and their quantities are very large. The hornblende is generally 2 mm, in some cases as large as 3 mm, and is often in the form of chlorite. The magnetite is smaller than 1.3 mm. The plagioclase is generally 2 ~ 1 mm, in some cases as large as 3 mm, and mostly is andesine. The groundmass shows hyalopilitic texture, and is composed of short strip type plagioclase, clay minerals, crystallite and glass.

(4) Upper Formation

The Upper formation is distributed on both banks of the Samala River at approximately 1,000 m south of Cantel, and is gently sloped at about 10° towards north. The upstream side of this formation is directly covered by the Cantel formation of the Cerro Quemado Group in unconformity relationship and its upper limit is not known.

The Upper formation consists of acid andesitic pumice flow deposits and air fall tuff breccia. The essential pumice of the pumice flow deposit is smaller than 10 cm in diameter and includes many andesite breccias as accidental materials. The air fall tuff breccia includes a large quantity of pumice. The thickness of these layers are estimated to be scores of meters.

(Description of Rock)

The description of the pumice as the essential material of the pumice flow deposits forming the Upper formation is as follows.

Specimen No. :	Nos. 73031909, and 73031911
Name of Rock :	Hypersthene-augite-biotite bearing hornblende acid andesitic pumice
Place of Sampling :	At 1,000 m south of Cantel

The white porous base is spotted with small phenocrysts of dark minerals.

Hypersthene, augite, biotite, hornblende and plagioclase are observed as phenocrysts and microphenocrysts, but their quantities are small. The hypersthene and the augite occur as short columnar idiomorphic crystals of 0.5 mm and 1 mm or less respectively. The biotite is smaller than 1.8 mm. The hornblende occurs as long columnar idiomorphic crystal smaller than 1 mm. The plagioclase occurs as long colmnar ~ short columnar, idiomorphic ~ hypidiomorphic form, and is mostly andesine. The groundmass is vitreous and includes small quantities of hornblende, biotite, plagioclase and crystallite.

1-2-3. Cerro Quemado Group

Most part of the Cerro Quemado Group intrude into the above-mentioned Zunil Group; and a part of it covers the latter as lava flows and pyroclastics. These used to be regarded as the Tertiary volcanic rocks, but judging from the well preserved form of volcanos, it is supposed that these are the results of activities in relatively recent stages of Pleistocene. The most recent rock in this area is the 1785 lava flow in Recent Period.

Most of these are distributed surrounding the Zunil Geothermal Area, and a part of them occurs in the geothermal area as hornblende andesite-rhyolitic or pyroxene andesitic intrusive rocks, or lava flows.

This Cerro Quemado Group is classified presumedly as follows mainly based on the forms of individual volcanic bodies. Generally in the order from the older ones, Almolonga lavas, Cerro El Galapago lavas, Volcan de Zunil lavas, Cerro Chuicham lavas, Cerro Quemado lavas, Cerro Tecum Uman lavas, Cantel formation, Cerro La Pedrara lavas, Zunil water-fall lavas, and 1785 lavas (Cerro Quemado), but the order of eruptions of these lavas will have to wait for further studies in detail over a considerably long period in the future.

(1) Almolonga Lavas

Almolonga Lavas are the hornblende andesitic body forming the base of the gigantic dome-shaped Cerro Quemado Volcano. The lava itself is a gigantic dome-shaped volcanic body with the diameters of approximate 5 km in north-south direction and 5 km in east-west direction.

A part of this dome cuts the Zunil Group in almost vertical direction. Namely, at the right bank of the Samala River just to the east of the junction of the dale running south from the Los Banos (Almolonga) Hot Spring and the Samala River, the alternation of pyroxene andesite lava and tuff breccia and the Almolonga lava have an almost vertical contact surface of N30°W of strike and NE85° of dip. The Almolonga lava here has very well developed columnar joints nearly perpendicular to this surface, or nearly horizontal.

The Almolonga lavas are intruded or covered by Cerro Quemado lavas, 1785 lava, Zunil water-fall lavas and Cerro El Galapago lavas.

(Description of Rock)

Specimen No. :	Nos. 73031204, 72031205, and 72031206
Name of Rock :	Augite-hypersthene bearing hornblende andesite
Place of Sampling :	Los Banos (Almolonga) Hot Spring and its downstream

This is a somewhat coarse-grained porphyristic rock with relatively large plagioclase and dark-mineral phenocrysts in the gray ~ grayish white base.

Augite, hypersthene, hornblende, magnetite and plagioclase are observed as phenocrysts and microphenocrysts. The augite occurs as short columnar idiomorphic crystals of 0.5 mm or smaller and the hypersthene as short columnar idiomorphic crystals of 0.8 mm or smaller. The hornblende occurs as long columnar idiomorphic crystals of less than 2 mm and is green hornblende with the peripheries turned opacite. The magnetite is smaller than 0.3 mm. The plagioclase is generally 1 ~ 1.5 mm, 2 mm at the maximum, long columnar ~ short columnar idiomorphic crystals and is in most cases andesine. The groundmass shows hyalopilitic texture and is composed of hornblende, pyroxene, magnetite, silica minerals, plagioclase and glass.

(2) Cerro El Galapago Lavas

The El Galapago lavas form the El Galapago volcanic body. This volcano is a stratovolcano of alternation of two pyroxene andesitic lava flow and tuff breccia. It has the crater on top with Las Majodas at the center and it is presumed that lava and volcanic products were emitted from the crater.

El Galapago volcanic body is located about 4 km east of and at the foot of María Volcano located on the southwest side and outside the present survey area, and it may be considered to be a parasitic volcano, but it needs further study.

El Galapago volcanic body has a diameter of approximately 2.5 km north-south and 2.5 km east-west and the crater is circular and has about 1 km of diameter. This volcanic body is considered to be in the intrusion relationship with Almolonga lavas and is presumed to be of nearly the same age as Volcan de Zunil lavas, Cerro Chuicham lavas, Cerro Quemado lavas, etc.

(Description of Rock)

Specimen No. :	73032007
Name of Rock :	Hypersthene-augite andesite
Place of Sampling :	Lava at the south entrance of tunnel to the north of La Estanica de la Cruz

This is a grayish brown ~ grayish black colored compact hard rock and is porphyristic rock with phenocrysts of plagioclase smaller than 2 mm and pyroxene.

Phenocrysts consist of hypersthene, augite, magnetite and plagioclase. Both the hypersthene and the augite are mostly short columnar idiomorphic crystals of 0.5 mm or smaller. The magnetite is 2 mm or smaller idiomorphic crystal. The plagioclase is long columnar - short columnar idiomorphic ~ hypidiomorphic crystal. The groundmass shows hyalopilitic texture and is composed of strip-shaped plagioclase; hypersthene, augite, magnetite, silica minerals, clay minerals and glass.

(3) Volcan de Zunil Lavas

The Volcan de Zunil lavas form two lava domes of approximate elevations of 3,000 m and 2,800 m to the east of Balneario Fuentes Georginas Hot Spring. They are volcanic bodies of hornblende-biotite andesite. These form volcanic bodies apparently different from the main peak of Zunil Volcano, which has not been surveyed yet, but as they are both considered to be lava domes, this name is adopted tentatively.

This volcanic body is considered to be a dome intruding into the Zunil Group, but a part of it flows down northwestward in a lava flow from the 3,000 m peak dome and covers the Zunil formation.

The relation with the other lava flows is not known because they do not come into direct contact, but judging from the fact that this volcanic body preserves the volcanic form relatively well, it is presumed that they are activities in nearly the same age as the aforementioned El Galápago Volcano, etc.

There is a still very active solfatara near El 2,740 m on the northwest slope of the 3,000 m peak and there are signs that it had been worked until recently as a sulphur mine.

(Description of Rock)

Specimen No. :	Nos. 73031501, 73031502, 73031504 (from 3,000 m peak dome) and 73031503 (from 2,800 m peak dome)
Name of Rock :	Olivine-augite bearing hornblende-biotite andesite
Place of Sampling :	El 2,700 m and El 2,500 m of northwest slope of 3,000 m peak and El 2,650 m of 2,800 m peak to the east of Balneario Fuentes Georginas Hot Spring

This is a gray ~ grayish white coarse-grained porphyristic rock with conspicuous plagioclase and dark minerals.

This rock is featured with many kinds of phenocrysts such as quartz, olivine, augite, hornblende, biotite, magnetite, plagioclase, etc. The quartz shows a corroded form and is smaller than 0.2 mm. The olivine is smaller than 1 mm, shows a corroded form, and is supposed to be a xenocryst. The olivine is in the form of short columnar idiomorphic crystal of 0.3 mm or smaller. The hornblende is in long columnar shape of 1 mm or less and is of brown hornblende type. The biotite is crystal of 1 mm or less. The magnetite is smaller than 0.3 mm. The plagioclase is in long columnar idiomorphic crystal smaller than 2 mm, and is mostly andesine. The groundmass shows hyalopilitic ~ microcryptocrystalline texture and is composed of hornblende, silica minerals, plagioclase and a large quantity of glass. Olivine-hornblende microgabbro-like accidental matters are observed in large quantities.

(4) Cerro Chuicham Lavas

The Cerro Chuicham Lavas are distributed on the southeast of Cantel, and include 3 unsurveyed domes of Jolom (2,890 m), Chuicham (3,278 m) and Chonajtauyub (2,947 m). The dome topography can be clearly seen from far away.

(5) Cerro Quemado Lavas

The Cerro Quemado Lava is a biotite-hornblende dacite dome intruding into the Almolonga lava, and shows composite dome topography around Candelaria, the main peak of Cerro Quemado volcanic body. These are called Cerro Quemado lavas collectively. This is a huge dome ranging 4 km east-west and 5 km north-south and is intruded by Cerro la Pedrera lavas and covered by 1785 lava.

(Description of Rock)

Specimen No. :	No. 73031201
Name of Rock :	Biotite hornblende dacite
Place of Sampling :	Banos Termales Los Vahos

This is a coarse porphyristic rock with conspicuous phenocrysts of plagioclase and dark minerals in grayish white base.

Biotite, hornblende, magnetite, quartz, plagioclase are observed as phenocrysts. The biotite is in plate shape smaller than 1 mm. The hornblende is long columnar idiomorphic crystal of 1.5 mm or smaller and is brown hornblende type, with opacite turned rim in some cases. The quartz is smaller than 1 mm and in a corroded from high quartz. The plagioclase is generally 1 - 2 mm, maximum 3 mm, long columnar idiomorphic crystal and mostly is andesine. The groundmass shows microcryptocrystalline ~ hyalopilitic texture, and is composed of biotite, hornblende, quartz, plagioclase and glass.

(6) Cerro Tecum Uman Lavas

The Cerro Tecum Uman Lavas form the Tecum Uman (El Baul) dome of El. 2,600 m located directly to the east of Quezaltenango City and are two pyroxene-hornblende andesitic. This dome is longer in the east-west direction and measures 1.5 km and the minor axis is in the north-south direction measuring o.5 km. Directly on the south of this dome, there are 6 domes formed by the Cerro La Pedrera lavas described in the later section, but the relationship with these domes is not known yet.

(Description of Rock)

Specimen No. :	Nos. 73031103, and 73031104
Name of Rock :	Augite hypersthene hornblende andesite
Place of Sampling :	Middle hill on the east and south of Cerro Tecum Uman

This is a coarse-grained porphyristic rock with conspicuous phenocrysts of plagioclase and hornblende in the gray ~ grayish brown base.

Augite, hypersthene, hornblende, magnetite and plagioclase are observed as phenocrysts. The augite and hypersthene are both short columnar idiomorphic crystals of 0.5 mm or smaller. The hornblende is long columnar idiomorphic crystal of 2 mm or less and is of brown hornblende type often with opacite turned rim, and in some cases has turned oxyhornblende. The magnetite is smaller than 0.2 mm. The plagioclase is long columnar idiomorphic crystal of 1.5 mm or less, and is labradorite ~ andesine. The groundmass shows hyalopilitic texture and is composed of hypersthene, augite, hornblende, magnetite, silica minerals, clay minerals and glass, and includes hornblende micrygabbroic accidental rock.

(7) Cantel Formation

In the area from Quezaltenango to the vicnities of Cantel and Zunil, there is a continuous and nearly horizontal lake deposits layer of volcanic products origin, and this is called the Cantel formation.

This layer is probably the lake deposits of the lake formed by the volcano-tectonic depression forming the present Quezaltenango Basin. This is presumed from the fact that a remarkable Bouguer anomaly of -160 mgal is confirmed nearly at the center of the basin and the basement rocks of this basin is subsided more than the other part of the Guatemala-Quezaltenango depression as described in III-3 (Fig. III-3).

The Cantel formation includes various types of subaqueous deposits such as tuff, tuff breccia, breccia, pumiceous tuff, lapilli tuff, pumiceous pyroclastic deposits, and partially includes diatom earth (Williams, 1960). There are also observed pumice flow deposits which seem to be terrigenous deposits.

(Description of Rock)

The description of the essential pumice in the pumice flow deposits included in the Cantel formation is as follows.

Specimen No. : No. 73031902

Name of Rock : Hornblende biotite rhyolitic pumice

Place of Sampling : Zunil, right bank of the Samala

Dark minerals of hornblende and biotite are dotted in porous white glass base.

Hornblende, biotite, magnetite and plagioclase are observed as phenocrysts, and microphenocrysts. The hornblende is short columnar idiomorphic crystal of 1 mm or less and is of green hornblende type. The biotite is in tabular crystal of 0.7 mm or less. The plagioclase is in short columnar idiomorphic crystal of 1.3 mm or less and is andesine ~ oligoclase. The magnetite is smaller than 0.1 mm. The groundmass is mostly glass, and includes small quantities of hornblende, biotite, plagioclase and crystallite.

(8) Cerro La Pedrera Lavas

The Cerro La Pedrera lavas are rhyolitic ~ dacitic lavas and intrude into and form lava domes and intrusive rock bodies of various sizes at many places in the present survey area, and make lava flows in some places. These show very recent volcanic activities, and as described in IV, 1-2-2, (1) briefly, they often intrude into the geothermal zones in the survey area and is considered to be closely associated with the passage for rising geothermal fluids from the deep underground part. Consequently, their occurrence and origin should be investigated in detail in the future.

These lavas are classified into two by the distribution areas, namely ① the group of 7 independent domes to the east of Quzeltanango City, and ② the group of 4 (or more) intrusive rock bodies distributed in the north-south direction in the Zunil Geothermal Area, and lava flows are observed in some parts of the latter.

The latter intrudes into the Zunil Group and the former into Almolonga lavas and Cerro Quemado lavas of the Cerro Quemado Group. The relationship with the Cantel formation is yet to be confirmed, but judging from the fact that a structure seemingly pushed up by the intrusion of a dome is found in a part of the Cantel formation; this is presumed to be activities after the deposition of the Cantel formation. Further it is supposed that they are closely associated with each other from the fact that these lavas closely resemble lithologically the pyroclastic rocks included in the Cantel formation.

The group of domes to the east of Quezaltenango City are arranged from the westernmost 2,740 m Peak on the north of Los Banos Hot Spring towards east in the order of la Pedrera Peak (2,560 m), the 2,665 m Peak, the 2,552 m Peak, the 2,540 m Peak, Cerro Huitan Peak (2,690 m) and the 2,600 ± m Peak.

These domes are arranged in nearly a line in the east-west direction, and suggests the underground structure in the same direction. Generally speaking, this line coincide with the direction of the Guatemala-Quezaltenango depression and represents the tectonic line running along the south border of the Quezaltenango Basin. Thus it is presumed that these dome group intruded along such a weak line. These domes measure 2 kn x 2 km at the maximum and 400 m x 400 m at the minimum, or 1 km x 1 km on an average, and the topography of the typical lava domes has been preserved very well.

It has been confirmed that the aforementioned small dome (IV, 1-2-2, (2)) at the junction of the Samala River and the Pachamiya River and 3 intrusive rock bodies distributed between Zunil and Fuentes Georginas Hot Spring intrude into the Zunil Geothermal Area in the southern part of the present survey area. The eastern rims of the latter 3 rock bodies are nearly in a straight line in the north-south direction, and this line may reflect the underground structural line (weak line) associated with the intrusion of these rock bodies. As stated before (iii-3 and III-5), the tectonic line in the north-south direction is closely associated with the N-S fault, etc. and deserves special attention.

On both sides of the above-mentioned small rock body at the junction of the rivers, the survey area's most dominant geothermal manifestations of Fumarole Grande and Fumarole Nagra are observed, and besides, the rock body to the east of Zunil Falls and the rock body including Fuentes Georginas and Aguas Amargas Hot Springs also are accompanied with similar fumaroles, hot springs and altered zones, etc. These rock bodies themselves are in some cases altered, and a part of the action is supposed to be deuteric alteration. Thus these rock bodies are directly related with the geothermal system in this area, and the clarification of these rock bodies is one of the important tasks.

It is added that both the banks of the Aguas Amargas Hot Spring valley intrude into the vicinity of Fuentes Georginas to the east, and they are supposed to be the lava flow that flowed down from this area, but almost all the others are intrusive rock bodies forming lava domes.

(Description of Rock)

The Cerro La Pedrera lavas are rhyolite or acid rock in between rhyolite and dacite, and therefore they will be called rhyodacite collectively. However the facies of such acid rocks very a great deal by the conditions of occurrence as shown on Table IV-2. These will be explained in the following.

As shown on Table IV-2, there are various rock types, but generally they are white ~ grayish white and sometimes pale yellow ~ pale yellowish brown glassy rocks spotted with a small quantity of dark minerals. They are classified into two types, porous and compact.

Augite, hypersthene, hornblende, biotite, magnetite, plagioclase, and rarely quartz are observed as phenocrysts. Both the pyroxenes are in very small quantities and are smaller then 0.2 mm. The hornblende shows generally 1 mm or smaller long columnar shape and is oxyhornblende, green hornblende and brown hornblende according to the rock bodies. The biotite is smaller than 1 mm and is in platy shape. The magnetite is smaller than 0.3 mm. Some rock types lack some of these dark minerals and some has lost those through alteration. The plagiolase is smaller than 2 mm, and some are fresh and some have turned into clay minerals, and it is andesine ~ oligoclase. The quartz is very rarely observed and is smaller than 1 mm. The groundmass is mostly vitreous and some are porous and pumiceous, some showing spherulitic texture, and some microcrytocrystalline texture and microfelsic texture.

(9) Zunil Water-fall Lavas

The Zunil water-fall lavas flow out from a corner at the south-east foot of Quemado Volcano and expands nearly in fan shape towards the Samala River. The lavas cover mainly the Zunil Group and partly the Cantel formation and are very recent (probably Historic period) lava flows. This lava flow is presumed to have reached the left bank of the present Samala River Valley formed by the Zunil Group and the Cerro La Pedrera lavas which projects in steep cliffs. As a result, the Samala River is stopped by this lava flow and a dammed lake was formed in the area of the Zunil Water-fall, and presumably still younger lake and alluvial deposits were stored on the bottom of the lake. And later, the present topography with the Zunil Water-fall and the V-shaped valley on the downstream was formed by severe erosion of the Samala River. Williams (1960) reported similarly in detail.

At a distant view, this lava flow forms a fairly wide and neary flat plateau which appears to be suitable for the power plant site. (To be described later, VII) However, this lava flow consists of dark gray blocky lava and considerable irregularity is seen on the surface. The thickness of lava is estimated to be 100 ~ 150 m at the maximum and the base part generally consists of compact lava. The lava in 20 ~ 30 m section from the basin of the Zunil Water-fall corresponds to this compact lava.

(Description of Rock)

Specimen No. :	Nos. 73031102, 73031302, 73031304, 73031305 and 7303153
Name of Rock :	Biotite hornblende dacite
Place of Sampling :	Vicinity of Zunil Water-fall

This is a coarse porphyristic rock with conspicuous plagioclase and hornblende in the grayish white ~ dark gray base.

Biotite, hornblende, magnetite, quartz and plagioclase are observed as phenocrysts. The biotite is smaller than 0.5 mm and its rim has been turned into opacite. The hornblende is mostly of long columnar ~ short columnar shape of 1.3 ~ 1 mm or less, and is oxy-hornblende. The magnetite is smaller than 0.3 mm. The quartz shows corroded ~ circular shape and is smaller than 1.2 mm. The plagioclase is mostly of long columnar and short columnar shaped idiomorphic crystal and is mostly andesine. The groundmass shows hyalopilitic texture and is composed of strip-shaped plagioclase, hornblende, biotite, magnetite, clay minerals, crystallite and glass. Plagioclase and augite are observed as xenocrysts and plagioclase augite showing microgabbroic ophitic texture is included as accidental rock.

(10) 1785 Lava (Cerro Quemado)

According to Williams (1960), this lava is reported to be blocky lava of hornblende-biotite andesite that flowed out at the time of the final eruption of Quemado Volcano in 1785, but the authors did not observe it directly.
(Note: According to the recent report by Gall, F. 1965, the final eruption of Quemado Volcano was in 1818 and this lava is ascribed to this eruption.)

1-2-4. Alluvial Deposits

The alluvium is observed as deposits on the lowlands in the mountain near Almolonga, Cantel and Zunil, on both banks of the Samala River, and as the alluvial fan on the downstream. It is observed often as talus and deposits due to landslides on fairly steep slopes. They include gravel, sand, clay and often recent volcanic products.

2. Geologic Structures and Geothermal Area

The Zunil Geothermal Area is, in a general view, located at the southern rim of the Guatemala-Quezaltenango Depression and the Quezaltenango Depression (volcano tectonic depression ?) which is supposed to be depressed especially in a basin shape and is controled by these geotectionics. Especially the east-west trending structure is presumed to represent this structure.

Directly related with the geologic structure of the Zunil Geothermal Area are; ① the underground distribution of the basement granites forming the depression, ② the stratigraphy and structure of the Tertiary Zunil Group covering this, ③ the occurence and the history of volcanic activitiesiintruding into and covering this, and ④ the relation between these formations and fault systems.

It is difficult to clarify these from the results of the survey in the very limited time, but the relationship between the notable geologic structures presumed through the survey and the geothermal system of the area and the problems to be clarified in the future are summarized in the following with the use of the following figures attached. However, considerable readjustment of these descriptions may prove necessary by the results of the detailed surveys in the future.

Fig. IV-1 Geologic Map of Zunil Geothermal Area

Fig. IV-2 Photo-Geologic Map of Zunil Geothermal Area (by Kokusai Geosurveys Co., Tokyo, April 1973)

Fig. IV-3 Explanatory Diagram of Zunil Geothermal Area

Notes : 1) Fig. IV-2 was prepared after the return of the Survey Team to Japan. Since accurate topographic correction was omitted, there remain some errors in this map, and the northern part has not been interpreted sufficiently for lack of photos.

2) Fig. IV-3 shows the complicated structures of the Zunil Geothermal Area in a simplified model form for convenience of explanation, and shows an approximately NW-SE profile of the geothermal area as viewed from the upstream.

(1) It is the Zunil Group filling the aforementioned depression and covering the basement granitic rocks that is expected to make the major geothermal reservoir in this area. Consequently, the state of existance of this group is influenced by the distribution and structure of the basement granites under this geothermal area.

The granitic rocks are distributed throughout underground in the Zunil Geothermal Area and the outcrops of these rocks are observed in inliers of various sizes in the east or northeast periphery of this area. And they were confirmed at depths of 250 m and 320 m from the ground surface by the two test borings for the Atitlan Development Program to the east of Cantel (Electro-Watt Co. 1971).

Based on these data, there is a possibility that the basement rocks may be reached at relatively near the surface in the geothermal area, too, and it is an important task to confirm it.

In general, granitic rocks are regarded as unsuitable for geothermal reservoirs except the special case accompanied by well developed fracture zones, and therefore it is not desirable that granitic rocks are distributed at shallow levels in the geothermal area.

It is generally believed that the reservoirs in this area consist of highly permeable tuff breccia and tuff of the Zunil Group and the less permeable compact lavas covering those make the cap rocks. Lavas with many joints and fissures make reservoirs in some cases. As the Zunil Group is believed to cover the weathered surface of the basement granitic rocks in unconformity relationship, the permeable weathered rocks and residual soils directly under the unconformity plane are presumed to make reservoirs. In short, the boundaries and unconformity planes between rocks of different permeabilities deserve special attention as geothermal reservoirs.

(2) The Zunil Group in this area slopes down gently towards north, and as shown in Fig. IV-1, the more north in the area along the Samala River, the more upper formation crops out. Consequently, in the southern part of the geothermal area where the most dominant Fumarole Negra and Fumarole

Grande are located, the lower formation outcrops and the depth to the basement rocks is smaller.

Especially at Fumarole Negra on the left bank of the Samara River, the lowest formation in this area crops out in a small size, around which the lower formation is distributed widely, showing that the basement rocks are distributed at the shallowest level in this area. For the Zunil Group to hold a powerful thermal source, a fair thickness of cap rock is desirable, though it may depend on the nature of the cap rock, the shallow basement rocks might present problems in the future. However, in the right bank area from Fumarole Grande, the middle formation crops out separated by the fault system to be mentioned later, and the basement is supposed to become deeper gradually and the conditions turn into better direction.

However, the Zunil Group confirmed on the surface of this area has a total thickness of layers of approximately 500 m, and the upper limit and the lower limit are still to be confirmed. Therefore, the thickness from the outcrop of the lowest formation at Fumarole Negra to the basement cannot be estimated at present. This will have to be confirmed by test borings and other physical prospecting in the future.

It may be an effective method to confirm the stratigraphy of the granitic rocks distributed scatteredly outside this area and the whole formations of the covering Zunil Group and compare them with this area. The total thickness and detailed stratigraphy of the Tertiary volcanic rocks in Guatemala comparable to the Zunil Group are not clarified so far, but the thickness measured by the aforementioned test borings at the Atitlan Project (Electro-Watt Co. 1971) is reported to be approximately 850 m at the maximum. The total thickness of the Zunil Group is estimated to be more than 1,000 m.

(3) Following the Zunil Group, there occurred the volcanic activities of the Cerro Quemado Group around this area and lava domes of various sizes, stratified volcanos and lava flows consisting mainly of andesites and rhyodacites were formed (1-2-3).

Quemado Volcano located to the west of the geothermal area which is a huge lava dome consisting mainly of Cerro Quemado lavas and Almolonga lavas, continued its activities until recently and emited the very recent Zunil Water-fall lavas and 1785 lavas. And judging from the fact that there is Santa Maria Volcano accompanied by the still active Santiaguito dome adjacent to the south of Quemado Volcano, it may be a common sense to presume that the magma reservoir as the thermal source is located under the ground to the west of the geothermal area as shown in Fig. IV-3.

The main upward passages for the geothermal fluids are considered to be the fault system and the fracture zones accompanying the faults, as shown in the figure. It is considered also that as described in 1-2-3 in detail, the highly viscous rhyodacites intruded into the geothe rmal area along such passages and formed independent domes of various sizes, causing fractures in the rock bodies around them by the pressure of intrusion, and the fractures make a part of effective passages in the present geothermal activities. For instance, Fumarole Grande and Fumarole Negra are located on both sides of a small dome and Aguas Amargas, Fuentes Georginas Hot Springs, the hot spring to the east of Zunil Water-fall, fumaroles and altered rocks, are all closely associated with the rhyodacite domes, as stated before.

(4) No definite conclusion can be drawn on the fault system in the Zunil Geothermal Area from the present survey of a very limited time, but the presumed faults are shown in Fig. IV-1 and the faults and the fracture systems interpreted from the aerial photos back in Japan are shown in Fig. IV-2. As is clear in these figures, this area has well developed NE-SW trending faults (or fractures), and some faults of NE-SE trend are also observed.

The 4 faults of NE-SW trand towards south from Zunil Village as shown in Fig. IV-1 all drop in step form on the NW side towards Quemado Volcano. These fault were presumed based on mainly the fact that the relatively flat plateau formed by the lower formation of Zunil Group and the lava plateau of the middle formation are cut by faults and caused differences in height. The throws of the faults are over 100 m. The fault running N65°E from the right bank on the south of Zunil Water-fall to Zunil Village cuts the Zunil Water-fall lava distinctly with a throw of about 30 m. The dome of the Cerro la Pedrera lava (described in 1-2-3) which is supposed to have intruded along the fault dividing Fumarole Negra and Fumarole Grande is in parallel with this NE fault system and is cut by small faults striking N35 ~ 55°E.

It is presumed that the right bank area of the Samala River has a deeper basement than the left bank influenced by the step faults system striking approximately in the NE-SW direction.

However, the NE-SW fault that cuts the cliff formed mainly by the andesite lava cropping out at the right bank of the Samala to the south of Cantel, only shows the contrary drop on the SE side.

Two NW-SE system faults were presumed in Fig. IV-1 Geologic Map. The one is the fault striking N70 ~ 75°W on the south of Aguas Amargas.

Hot Spring and with the drop on the north side, which is presumed from the fact that it divides the middle and the lower formations of the Zunil Group. The other is the suspected fault striking N60°W on the upstream side of Zunil Village.

The fault system on the geologic map and the fault system on Fig. IV-2 Photo-geologic Map agree relatively well, but careful observation reveals some discrepancy in that the NE-SW system faults show strikes of N50 ~ 60°E, while those in the photo-geologic map show mostly N35 ~ 50°E. These will have to be studied into in detail in the future survey.

Williams (1960) assumed a big fault striking NNE between Zunil Volcanic Group and the Samala River approximately in parallel with the Samala, and assumes that it is a faulting movement of the same tendency as the Guatemala City Graven which was described before. Similar tendencies of faults and fracture systems are observed in the two geologic maps prepared in the present survey and they deserve careful attention.

As stated before in 1-2-3, the domes and intrusive rock bodies formed by the Cerro la Pedrera lavas are arranged in the E - W direction on the south of Quezaltanango City, and in nearly N - S direction between Zunil and Fuentes Amargas Hot Spring. These are presumed to suggest the underground tectonic lines striking E - W and N - S and it is presumed that the rock bodies intruded along those tectonic lines.

3. Hydrothermal Alteration

Many geothermal manifestations such as fumaroles, solfataras, hot springs, altered zones, etc. and accompanying altered rocks of various kinds are observed in the Zunil, Moyuta and Ahuachapan Geothermal Areas. Detailed studies of these altered rocks reveal the temperature, pressure, chemical compositions, rising mechanism, etc. of the underground thermal water, and are applied in direct and indirect prospecting of the geologic structure, estimation of the scale, etc. of the geothermal areas. The authors could clarify the general features of the geothermal areas, by laboratory tests of the samples collected fragmentarily during the present survey of a very limited period. Further detailed study is to be expected.

The results of detailed studies made after the Survey Team's return to Japan with the samples with respect to the color, hardness, mineral constituents, pH value of the immersion solution*, are tabulated in Table IV-3. The X-ray diffraction patterns of some typical altered rocks are shown in Fig. IV-4.

It has been confirmed by the tests that most of the altered rocks from the Zunil, Moyuta and Ahuachapan (El Salvador) Geothermal Areas Suffered typical acid type hydrothermal alteration and contain cristobalite, quartz, alunite, kaolin, etc. as the characteristic altered minerals. The so-called silicified rock containing much crystobalite and quartz in the altered rocks suggests the existence of dominant deep thermal water under the ground.

In a part of the altered rocks from the Azulco outcrop and the bore core at Ahuachapan, there occur zeolites (wairakite and laumontite) suggesting the existence of neutral ~ weakly alkaline deep thermal water. In the Zunil Area, however, no zeolites were observed, and all the altered rock samples collected are considered to be formed by the acid type alteration. (No sample of altered rock could be collected from Fumarole Grande where the salt spring type deep water of pH 9.0 containing about 700 ppm of Cl springs out in a geyser.) It was noted especially that the pH values of the immersion solutions of the altered rocks from the vicinity of the Sulfur Mine were remarkably low and nearly 1.

In general, even in case the deep water is neutral ~ weakly alkaline, the water in many cases is turned acidic or strongly acidic near the ground surface and on the surface through oxidation by the descending ground water and air. (e.g. Otake in Japan and Wairakei in New Zealand) Therefore, it cannot be concluded by the tests of rather few samples collected in the present survey that the deep thermal water under the ground near the Sulphur Mine in the Zunil Geothermal Area is strongly acidic. However, the remarkably low pH value of the immersion solution should be noted in the future geothermal development.

3-1. Zunil Geothermal Area

There are many geothermal manifestations of fumaroles, solfataras, geysers, hot springs, altered rocks, etc. and there is no doubt that this is an active geothermal area. For convenience of description, the area is devided into 4 areas, namely Fumaroles Grande-Negra Field (downstream of the Pachamiya), Fumarole Paxmax Field, Fuentes Georginas Field and Sulphur Mine Field.

Among these 4 fields, the most dominant geothermal manifestations are observed in Fumarole Grande-Negra Field as described in V. 3-1 (Chemistry of Geothermal Area). From the view point of the altered minerals, this field has

Foot Note *: pH value of distilled water immersed with the powder of the altered rock. It is considered to show a value near the pH value of the hydrothermal solution which caused the alteration. (HAYASHI, 1973) silicified rocks distributed at many places indicating the existence of hot deep water and the pH values of the immersion solutions do not show strong acidity, and this field is considered to be most promising.

As stated before, Fumarole Grande and Fumarole Negra are closely associated with the small rhyodacite domes of Cerro Pedrera lavas (1-2-3 (8)) separating these fumaroles and the NE fault. This NE fault extends towards north and reaches Fumarole Paxmax where another rhyodacite dome intrudes similarly.

Fuentes Georginas Field and Sulphur Mine Field are apart from the above two fields on the south, and no direct association can be observed. Since the pH values of immersion solutions of altered rocks from these fields show strong acidity of nearly 1, if high temperature water is obtained, it might show too strong acidity to be used for geothermal power generation. It is necessary to define the expansion of this strongly acidic zone with more samples collected in the future.

3-1-1. Fumarole Grande-Negra Field

On the left bank in this field outcrop basaltic andesite and rhyodacitic phroclastics of the lower ~ lowest formation of the Zunil Group, and on the right bank pyroxene andesitic lavas and their tuff breccias, which are intruded by the aforementioned small rhyodacite domes.

Most of these rocks have turned into silicified rocks of mainly cristobalite. Especially, with Specimen 73031211 (Fumarole Negra) the basaltic rock has completely been altered into cristobalite showing that it suffered strong alteration. (Fig. IV-4, ①) Specimen 73031209b contains cristobalite and quartz. (Fig. IV-4, ②)

Specimen 73031215 is the only one sample containing alunite. (Fig. IV-4, ③) Alunite indicates the condition of sulphuric acidity and at the same time is likely to be formed in case the deep thermal water contains much SO_4. Consequently, less distribution of this mineral is more favorable for geothermal power generation. The distribution of alunite must be also confirmed by the future survey.

The pH values of immersion solutions of the altered rocks in this field are in a range of 3 ~ 4, which are values commonly observed in fumarole zones of many geothermal areas. Thus it is presumed that the deep thermal water in this field is at least neutral ~ weakly alkaline, and if it is acidic, the acidity would not be so high as unsuitable for geothermal power generation.

3-1-2. Sulphur Mine Field and Fuentes Georginas Field

Fuentes Georginas Field is formed by relatively large rhyodacite intrusive body of the same nature as the Zunil Group and the small domes in the foregoing field. This rhyodacite body is spotted with fumaroles, solfataras and altered zones, and acid hot spring of Fuentes Georginas (pH 2. 1) and Aguas Amargas (pH 2. 2) spring out from this rock body. Sulphur Mine Field is located on the slope of the lava dome of Volcan de Zunil lava (hornblende-biotite andesite) to the east and is an altered zone with active solfataras.

The immersion solutions of the altered rocks in this area show remarkably strong acidity of about 1 of pH value. In general, the altered rocks near solfataras often show strong acidity of pH 1 ~ 2, but it seems rather abnormal that this strong acidity of pH 1 or so is distributed over such a wide area as Fuentes Georginas Field and Sulphur Mine Field combined. Judging from very limited number of surface samples, there is a possibility that the deep thermal water from these fields may not be suitable for geothermal power generation.

The altered rocks (clay) contain much amorphous materials (Fig. IV-4, ④), and the typical Specimen 73031502 contains no crystalline material. (Fig. IV-4, ⑤ It is necessary also to determine the chemical composition of such amorphous materials.

3-1-3. Paxmax Fumarole Field

This field is adjacent on the north to Fumarole Grande and is intruded similarly by a rhyodacite dome and is considered to be associated with Fumarole Grande through the NW fault connecting the two fields.

Two samples of altered rocks were collected from the altered zone with fumaroles on the slope of the rhyodacite dome. The one consists of cristobalite (Fig. IV-4, ⑥), and the other of alunite and feldspar (relic mineral ?) (Fig. IV-4, ⑦). The immersion solution of the former is acidic and that of the latter is strongly acidic.

3-2. Moyuta Geothermal Area

Guinea and Marucuccy Fields are located about 3 km to the northwest of Moyuta and Azulco Field about 5 km north-northeast of Moyuta. They are all in the area where Quaternary andesitic ~ basaltic lava is distributed.

3-2-1. Guinea and Marucuccy Fields

The muddy materials altered rocks, in and around the fumaroles show acidity of pH 2 ~ 3 in immersion solutions and they contain cristobalite, montmorillonite, stilbite, gypsum, etc. (Fig. IV-4, ⑧ and ⑨) However, alunite, characteristic of acidic fumaroles and solfataras, is contained in small quantity only in Specimen 73030503c. The pH value of the immersion solution agrees with an average value of general fumaroles.

3-2-2. Azulco Field

The immersion solutions of all the samples show pH values of 6 ~ 7. The fact that wairakite and laumontite are contained in the rocks indicates that the deep thermal water in this field is neutral ~ weakly alkaline, and it is expected that it is suitable for geothermal power generation with adequate pH values. These zeolites, especially wairakite, are the characteristic minerals of the first reservoir (at depths of 300 ~ 500 m) in Otake Geothermal Area in Japan, and they cannot be considered to be formed in the shallow place under the ground. The silica minerals are all quartz and do not contain cristobalite which is formed at low temperatures. Therefore, it is supposed that the altered rocks at El. 740 ~ 900 m, from which the samples were taken, formed the present projecting small hill by faulting or erosion after it suffered hydrothermal alteration deep under the ground.

3-3. Ahuachapan Field

The samples from the fumaroles, hot springs and altered zones on the surface show acidic pH values in immersion solution, and contain cristobalite, alunite, kaoline, etc. (Fig. IV-4, ⑪) On the other hand the bore core (at unknown depth) of No. 10 production well consists of wairakite and chlorite (Fig. IV-4, ⑫) and suffered neutral type alteration.

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Table IV-1 Geologic Succession of Zunil Geothermal Area, Southeast of Quezaltenango City* (26th. May, 1973)

Geologic Age		Geologic System		Rock Type
Quarternary	Holocene	Alluvial deposits		Gravel, Sand, Clay, Volcanic ash
Quarternary	Holocene	Cerro Quemado Group	1785 lava (Cerro Quemado)	Biotite hornblende andesite
Quarternary	Holocene	Cerro Quemado Group	Zunil water-fall lavas	Biotite hornblende dacite
Quarternary	? Pleistocene	Cerro Quemado Group	Cerro La Pedrera lavas	Au Hy bg Bi Hr glassy rhyodacite Au Hy Bi bg Hr spherulitic rhyodacite
Quarternary	Pleistocene	Cerro Quemado Group	Cantel formation	Tuff, Tuff breccia, Hr Bi rhyolitic pumice flow deposit, Conglomerate, Diatom bed? etc.
Quarternary	Pleistocene	Cerro Quemado Group	Cerro Tecun Uman lavas	Augite hypersthene hornblende andesite
Quarternary	Pleistocene	Cerro Quemado Group	Cerro Quemado lavas	Biotite hornblende dacite
Quarternary	Pleistocene	Cerro Quemado Group	Cerro Chuicham lavas	(not observed yet)
Quarternary	Pleistocene	Cerro Quemado Group	Volcan de Zunil lavas	Q Ol Au bg Hr Bi andesite
Quarternary	Pleistocene	Cerro Quemado Group	Cerro El Galapago lavas	Hypersthene augite andesite
Quarternary	Pleistocene	Cerro Quemado Group	Almolonga lavas	Augite hypersthene bg hornblende andesite
Tertiary		Zunil Group	Upper formation	2 pyroxene biotite bg hornblende acid andesitic pumice flow deposit, Tuff breccia etc.
Tertiary		Zunil Group	Middle formation	Olivine pyroxene andesite, 2 pyroxene andesite, Augite hypersthene hornblende andesite, Hornblende andesite, these lava and tuff breccia
Tertiary		Zunil Group	Lower formation	Hornblende biotite rhyolitic pumice flow deposit, Air fall deposit
Tertiary		Zunil Group	Lowest formation	Olivine hypersthene augite basaltic andesite tuff breccia
Mesozoic		Basement rocks		Bi granite, Hr Bi granodiorite, Q porphyry

Au:augite Bi:biotite Hr:hornblende Hy:hypersthene Ol:olivine Q:quartz bg:bearing

* (1) This is a preliminary note of the result of geological reconnaissance during 11-20th, March, 1973.

(2) It will be revised by the detailed survey in future.

Table IV-2. Rock Type of Cerro La Pedrera Lavas

Sample No.	Rock Type (rock name)	Locality
73031202	Au Hy bg Bi Hr glassy RD	2740 m Peak
73031203	Au bg Bi Hr glassy RD	Cerro La Pedrera
73032001	Au Hy bg Bi Hr spherulitic RD	2600 m Peak
73031213 73031214 73031604	Au Hy bg Hr Bi spherulitic RD altered RD	Lower reaches of Pachamiya River Left side of Samala River
73031216 73031511	Bi RD	Zunil NWW
73031507 73031508 73031509	Au Hy Bi bg Hr glassy RD Au Hy Bi bg Hr spherulitic RD	Tzanmucubal W
73031505 73031608 73032002 73032003 73032004	(Q Hy) Au bg Hr Bi glassy RD ～ Au bg Hr Bi spherulitic RD ～ altered RD	Balneario Fuentes Georginas ～ Balneario Aguas Amargas

Au: augite　　Bi: biotite　　Hr: hornblende

Hy: hypersthene　　Q: quartz　　RD: rhyodacite

bg: bearing

Table IV - 3 Mineral Constituent of Altered Rocks from the Geothermal Areas, Zunil, Moyuta and Ahuachapan
(T. Yamasaki, Y. Matsumoto, and M. Hayashi, 1973)

Locality		Specimen No.	Color	Hardness	Mineral Constituents												pH*	
					Am	Cr	Qu	Al	Ka	Mo	Ch	La	Wa	Fl	Un	other minerals		
Zunil	Fumaroles Grande-Negra	73031209a	reddish brown	soft	○	○	○									An	3	Altered rocks formed in the Lowest formation of Zunil group
		73031209b	pale brown	soft		◎										An	1	
		73031209c	white	hard		◎											4	
		73031211	very pale brown	medium		◎											4	Altered from basaltic rock
		73031213	medium gray	hard	◎												3	Altered rock from rhyodacitic tuff breccia in a fumarole
		73031214	pinkish gray	medium		○								○			3	Altered rock from rhyodacite in a fumarole
		73031215	very pale brown	medium		○		◎									3	Altered from intrued glassy rhyodacite
	Sulphur Mine	73031502	very pale brown	soft	◎											An	1	Altered rocks near the Sulphur Mine
		73031502	light gray	soft	○	○	○										1	
	Fuentes Georginas	73031505a	white	soft	◎		∘										1	Altered rock in a fumarole
		73031505a	medium gray	medium	◎	∘											1	
		73031506	white	soft				◎	∘								1	
	Paxmux Fumarole	73031512a	white	soft		◎											4	Altered rock from rhyodacite in a fumarole of Zunil water fall
		73031512b	light gray	soft		○		○						◎			1	
Moyuta	Guinea	73030503a	yellow	soft		○				○!					○	Gp	1	Altered rock near fumaroles
		73030503b	yellowish gray	soft		○				◎					∘	Gp, Pt	2	
		73030503c	white	medium		○		∘	○								3	
		73030503d	light gray	soft										◎	∘		2	Mud in a fumarole
	Marucuccy	73030504a	grayish pink	soft	◎	○	∘										3	Ditto
		73030504b	dark brown	soft						○						Gp, St	3	Ditto
	Azulco	73030601a	grayish green	hard			○			∘!				◎		Ca, Pt	6	Altered rocks at 900 m in altitude
		73030601a	white (vein)	medium			◎			∘			○					
		73030601b	medium gray	hard						○				◎		Ca	6	
		73030602	graish green	medium							○	○		○	∘	Pt	7	Ditto at 880 m in altitude
		73030602	white	soft								◎		○			7	
		73030604	very pale brown	soft						○		◎				Ca	6~7	Ditto at 820 m in altitude
		73030605	white	hard			◎									Ca		Ditto at 740 m in altitude
Ahuachapan		73030701	white	soft		◎			○							Pt	3	Mud in a fumarole
		73030701	light gray	soft	◎	○	∘	○									3	
		73030702	grayish green	medium							∘		◎	○		Ca	7	Core of No. 10 well

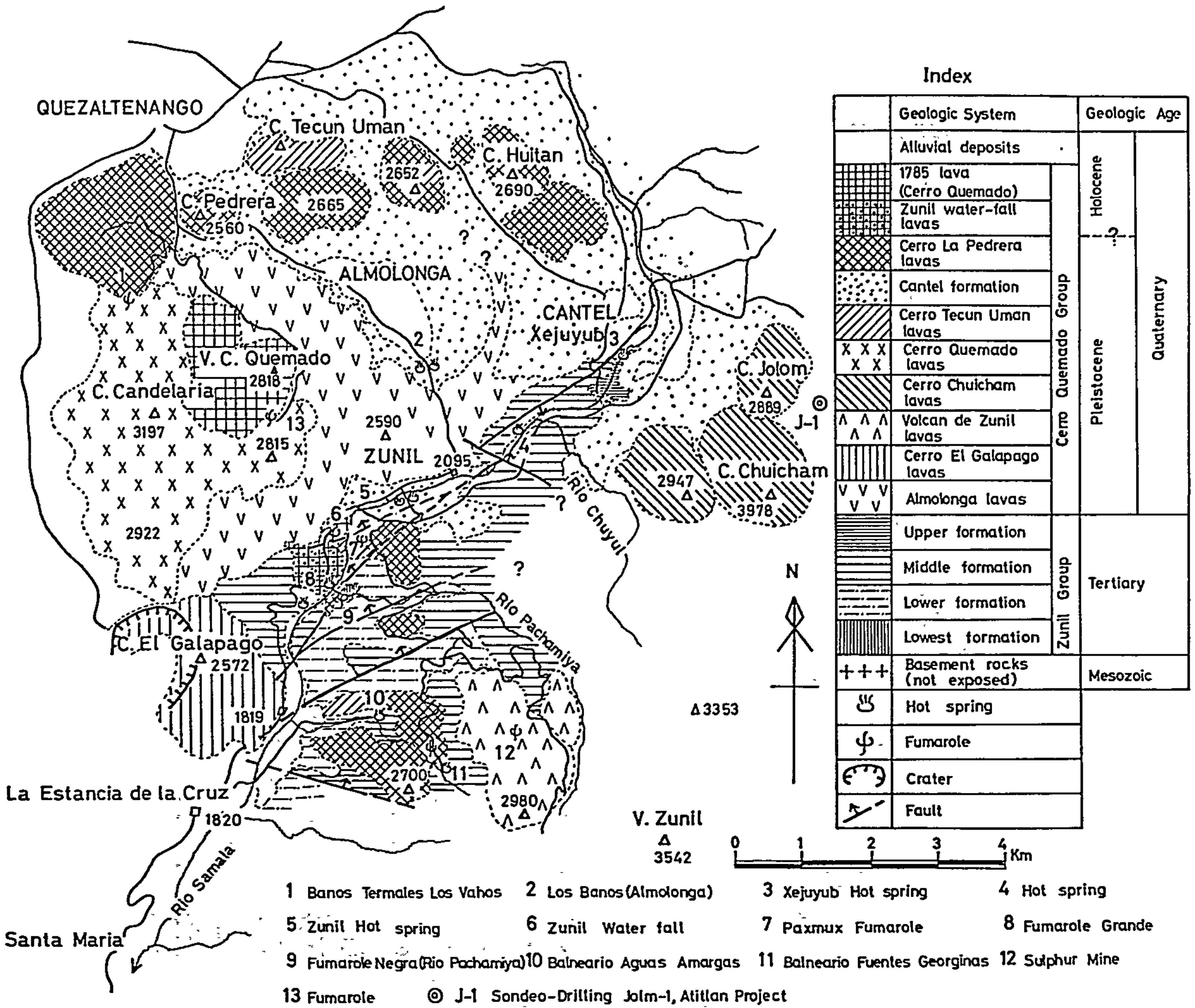
◎ predominant
○ common
∘ rare

Al: alunite Am: amorphous An: anatase Ca: calcite Ch: chlorite Cr: cristobalite Fl: feldspar Gp: gypsum
Ka: kaolin La : laumontite Mo: montmorillonite Pt : pyrite Qu: quartz St: stilbite Un: unknown Wa: wairakite

* The pH value of distilled water in which rock powder is immersed.

Fig. IV-1. Geologic Sketch Map of Zunil Geothermal Area, South-east of Quezaltenango City, Guatemala

(YAMASAKI and MATSUMOTO, 11th~20th. March, 1973)



1 Banos Termales Los Vahos 2 Los Banos (Almolonga) 3 Xejuyub Hot spring 4 Hot spring

5 Zunil Hot spring 6 Zunil Water fall 7 Paxmux Fumarole 8 Fumarole Grande

9 Fumarole Negra (Rio Pachamiya) 10 Balneario Aguas Amargas 11 Balneario Fuentes Georginas 12 Sulphur Mine

13 Fumarole ◎ J-1 Sondeo-Drilling Jolm-1, Atitlan Project

Fig. Ⅳ-2 Photo-Geologic Map of Zunil Geothermal Area, Guatemala
(by Kokusai Geosurveys Co. Japan, April, 1973)

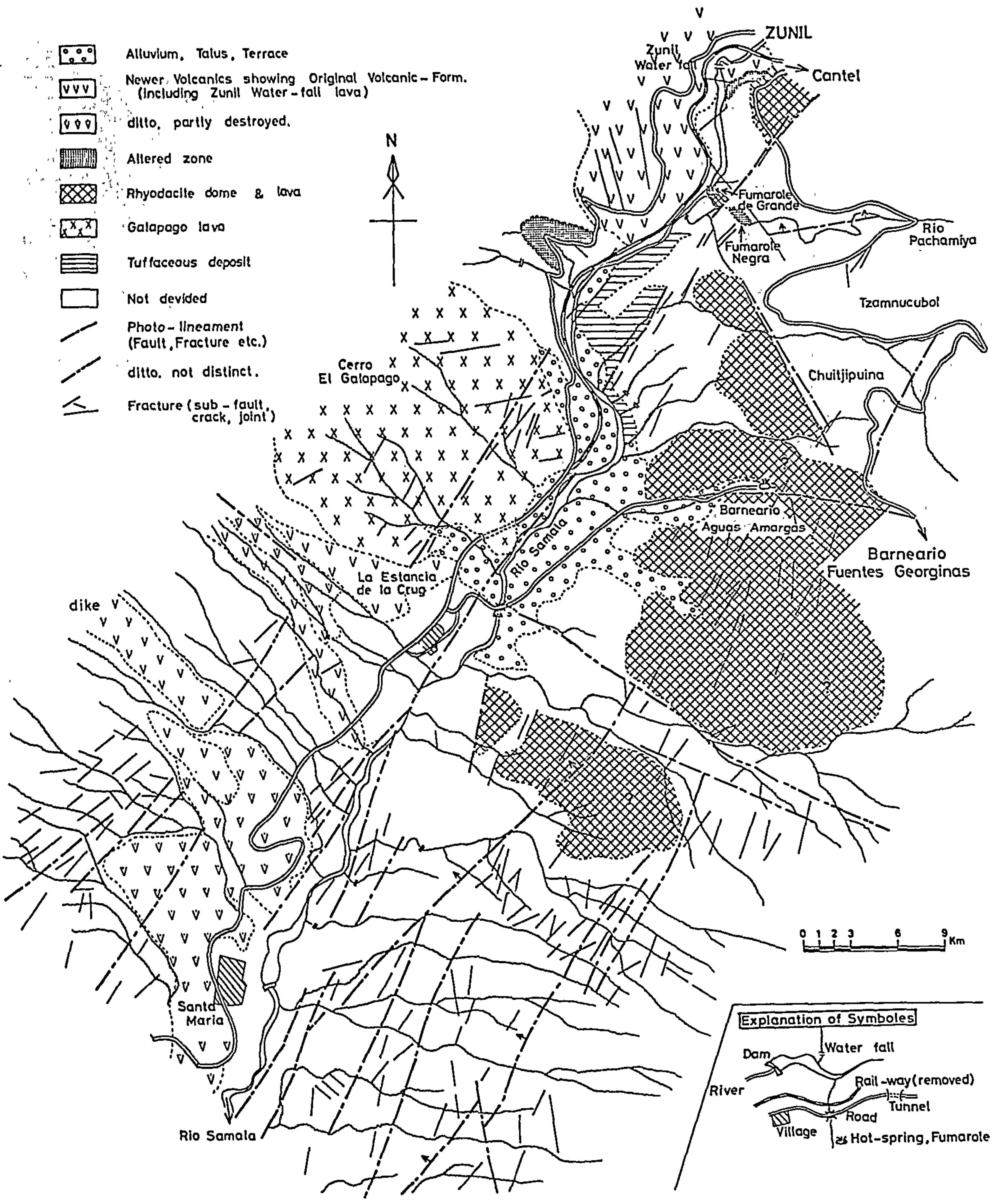


Fig. IV-3. Explanatory Diagram of ZUNIL Geothermal Area, Guatemala

(YAMASAKI and MATUMOTO, 1973).

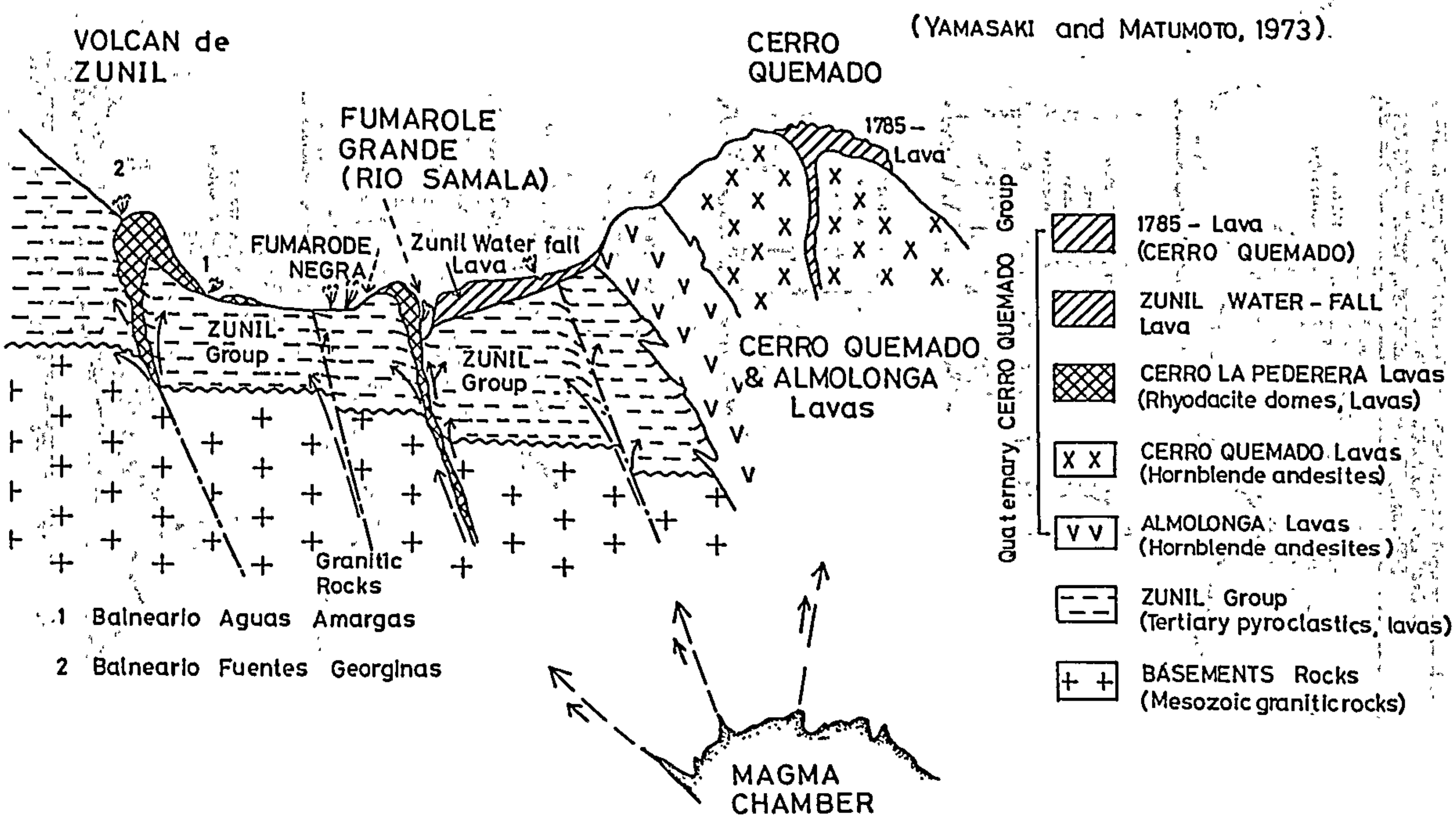


Fig. IV-4a. X-ray Diffraction Patterns of Altered Rocks from Zunil Geothermal Area, Guatemala
(YAMASAKI, MATSUMOTO and HAYASHI, 1973)

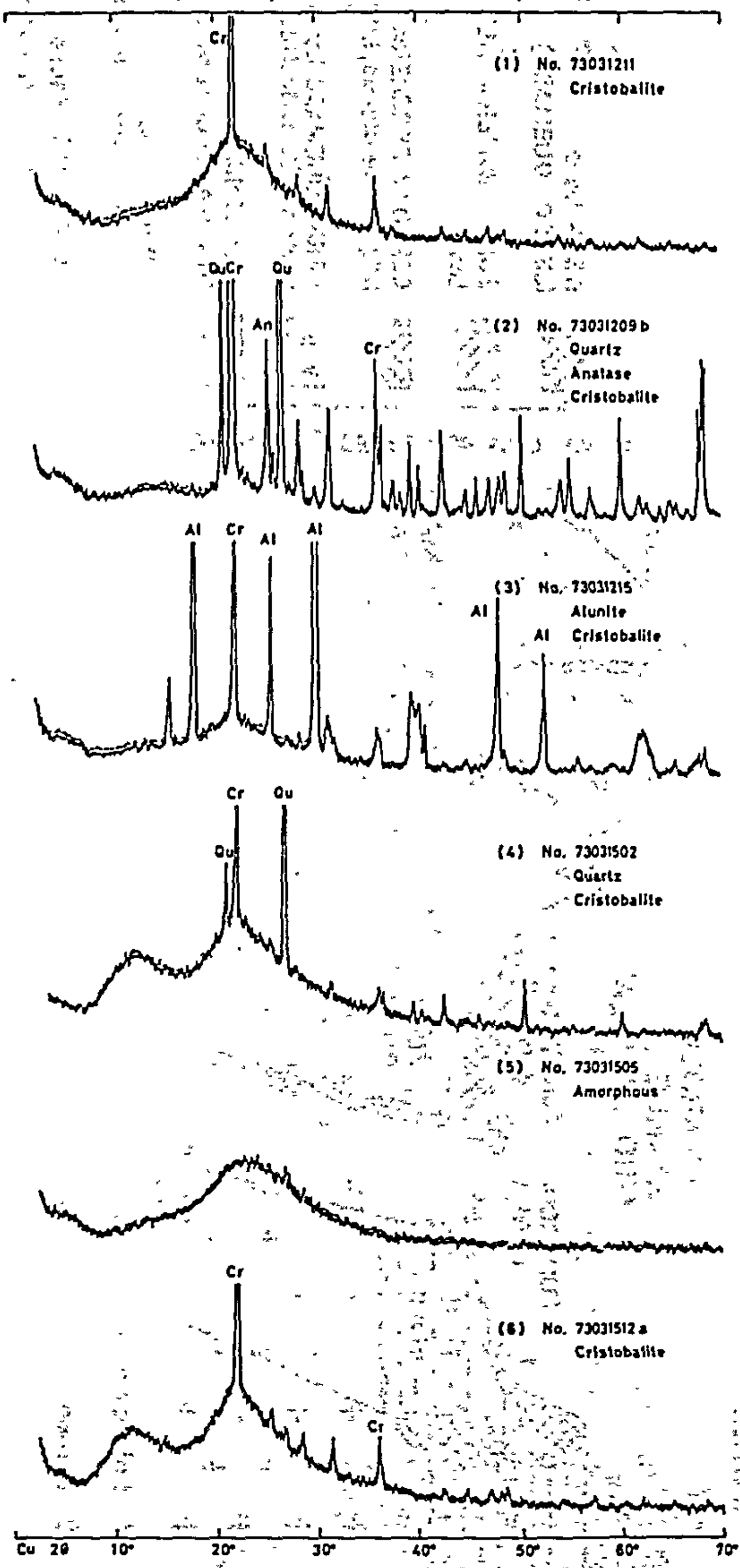
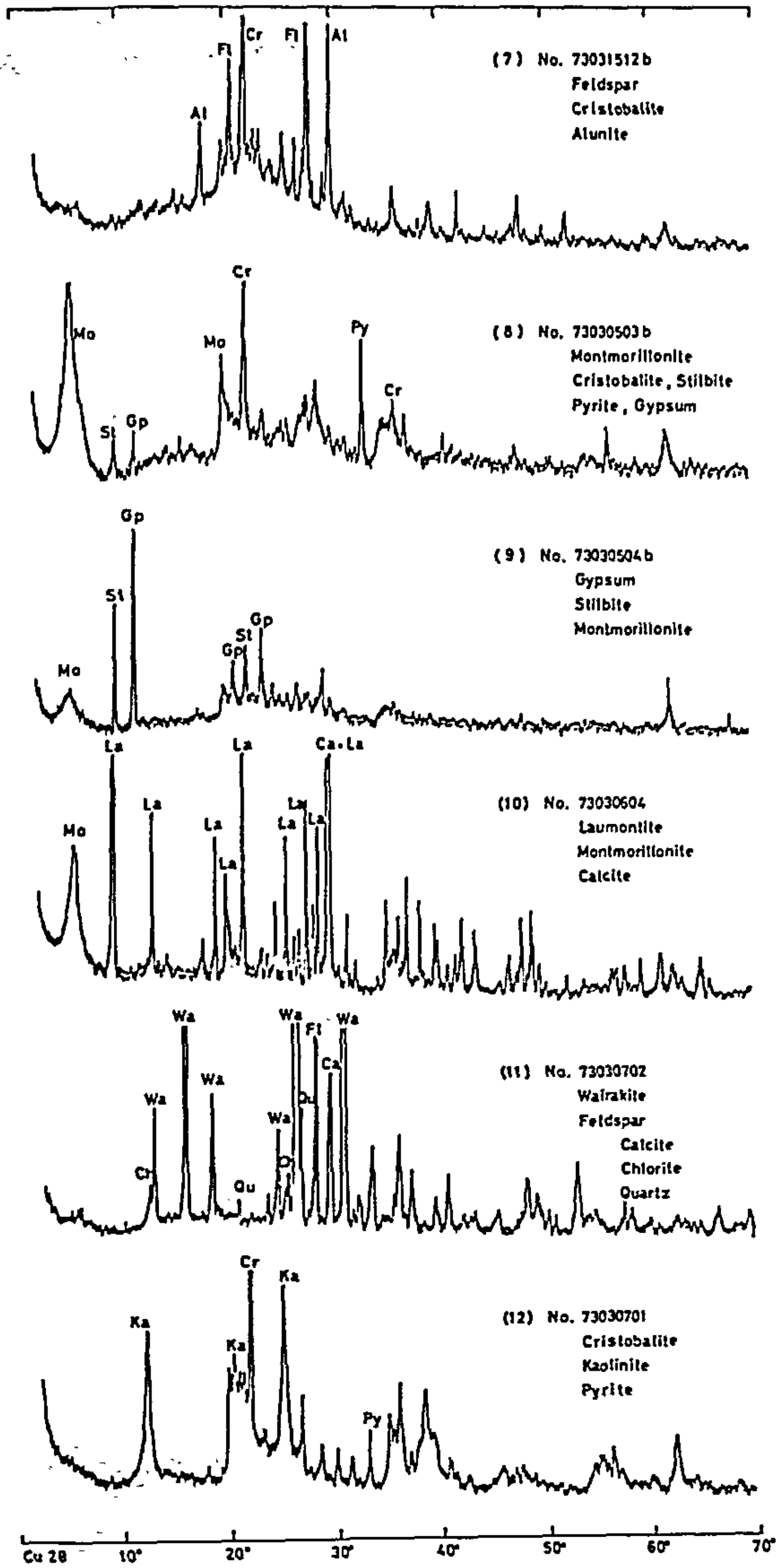
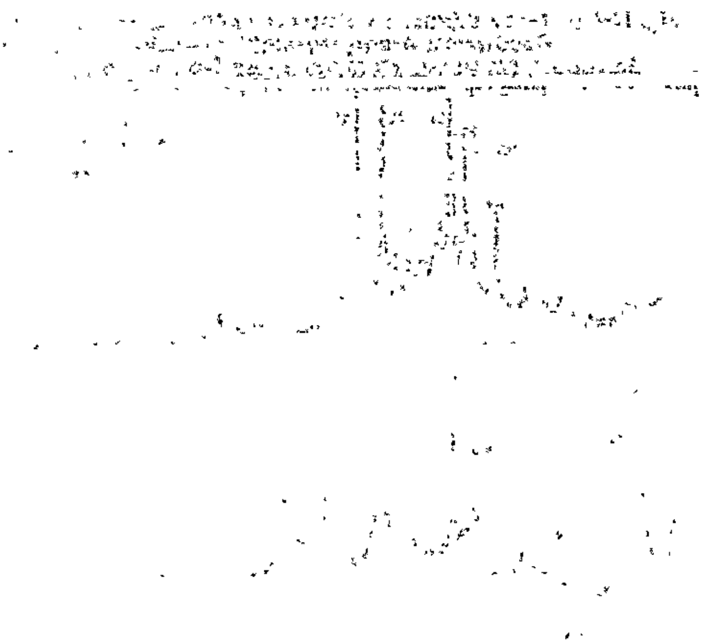
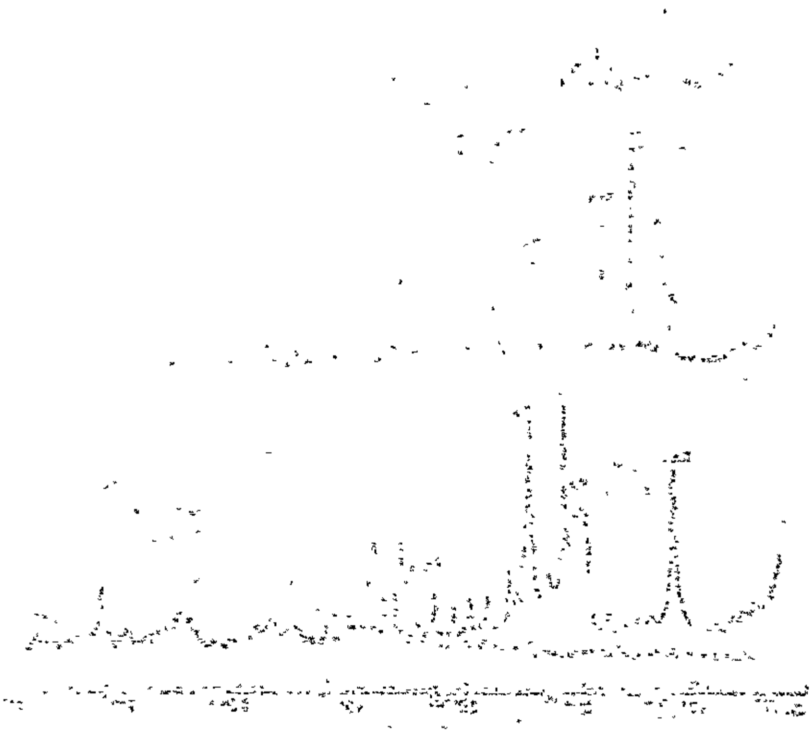


Fig. IV-4b X-ray Diffraction Patterns of Altered Rocks from Geothermal Areas, Moyuta(Guatemala) & Ahuachapan(El Salvador), (YAMASAKI, MATSUMOTO and HAYASHI, 1973)







CHAPTER V GEOCHEMISTRY OF GEOTHERMAL AREA

1. Introduction

Chemical analysis of natural hot spring water is made as a good guide to the geothermal development. Quantitative measurement of various components and determination of ratios between those components give information on the temperature of the underground aquiter, types of rocks, and further the origin and formation of the hot spring water. These methods of obtaining information are based on the reaction between the rock minerals and water and the solubility under certain temperature and pressure conditions. Of course, dilution by surface water, separation of vapor and the factors influenced by pH must be considered in all cases. The analytical data of hot spring water and fumarole gases prove to be very effective aids to more detailed survey of promising areas and test borings for geothermal power generation.

In the preliminary survey of the geothermal areas in Guatemala, 36 samples of hot spring water were taken. Fig. V-1 shows the distribution of hot spings in Guatemala. Water samples were taken from the typical hot spings, namely 3 samples from San Marcos, 11 samples from Zunil, 5 samples from around Lake Amatitlan, 4 samples from Ixpaco, 9 samples from Moyuta, 1 sample from El Coco, 1 sample from Asuncion Mita, 1 sample from the generation well of Ahachapan in El Salvador and 1 sample from a nearby fumarole area. Aside from those water samples, 5 samples of condensed water of the fumarole vapor and 13 samples of alteration products at various places were taken. Analysis of fumarole gas at Zunil was also made for the same purpose.

2. Geochemistry for Geothermal Development

In determining the most promising area for geothermal development by the analysis of hot spring water, the method differs for (1) the hot water system and for (2) the steam system.

2-1. Hydrothermal System

When there are many high temperature and large discharge hot springs, the following chemical components of hot water as considered to give indication of the underground temperature (White: 1970)

1)	High SiO_2	High temperature
2)	Low Na/K and low Na/Li	"
3)	High Cl/total carbonate species	"
4)	High Na/ Ca	"
5)	Low Ca and HCO_3	"
6)	Low Mg and low Mg/Ca	"
7)	High Cl/F	"
8)	Siliceous sinter deposit	$T > 180°C$
9)	Calcareous sinter deposit	Low temperature

Hot springs meeting these conditions can be considered to originate from high temperature aquifers. These indicators, however, should not be considered individually, but should be treated compositively. The studies of hot springs in Guatemala was made along this line.

To mention the behavior of other elements breifly, Cl and B are soluble elements and once they leave rocks, they would not enter the structure of secondary minerals readily. Consequently, when the Cl/B ratios are compared with various hot springs, if the ratios are the same, those hot springs can be judged to originate from the same aquiter, because the ratio is not affected by dilution and evaporation. The Cl/B ratio, however, decreases, if the water passes through sedimentary rocks, and B is high in the steam phase. Therefore, the Cl/B ratio tends to be smaller with steam heated water.

NH_4 originates usually from organic matters commonly included in the sedimentary rocks, and as it is volatile, it is carried by vapor, and the quantity of NH_4 indicates the existence of sedimentary rocks and whether the system is a steam heated system or not.

Li is found in high temperature water and low Na/Li ratio indicates a high temperature aquifer. The concentrations of Ca, Mg and F are controled by the solubilities of calcite, anhydrite, chlorite, fluorite and Ca-Al-silicate, and the higher the temperature the lower the solubility. Therefore, high Na/Ca, Na/Mg and Cl/F ratios generally indicate high temperature underground.

It is known by experiments on the reaction between rocks and water under high temperature and high pressure conditions, that the Na/K ratio of water of 180°C or higher, depends upon the temperature and pressure. (Ellis, Mahon 1964, 1967) If the high temperature water from deeper parts and the low temperature water from shallow parts are mixed, the Na/K ratio increases, and vice versa. The Na/K ratio method is used for computing the temperature with neutral salt spring type water, but this ratio in the hot spring water at 200°C or below is liable to cause error. This method can neither be applicable to acid hot springs nor to water of high HCO_3 and SO_4 content. (Koga, 1972) Therefore, checks must be made simultaneously with other indicators.

The SiO_2 concentration of hydrothermal water of 110°C or over in controlled by the solubility of quartz. Therefore, it is possible to calculate the temperature of the underground aquifer by the concentration of SiO_2 in the hot spring water rising from the depth underground rapidly without dilution. (Fournier, Rowe, 1966)

Siliceous sinter and geysers occur probably at places where the underground temperature is 180°C or over, but calcareous sinter occurs only at places of low temperature.

SO_4 is controled by anhydrite solubility, and decreases at high temperature. In the steam heated water, the Cl/SO_4 ratio is low due to oxidation of H_2S carried in the water vapor.

The quantity of HCO_3 differs by the CO_2 pressure and rock minerals, but occurs presumably by the reaction,

$$CO_2 + H_2O + (Na,\ K)\ \text{silicate} + (Na^+,\ K^+) + HCO_3^- + \text{H-silicate}.$$

Since this reaction is slow, the Cl/HCO3 ratio of water will remain unchanged, even if the SiO_2 concentration and the Na/K ratio are affected by the reaction near the ground surface. The steam heated water has high HCO_3 content and consequently the $ClHCO_3$ ratio is small. In general, the larger the Cl/HCO_3 ratio, the deeper the thermal water originates and the higher the temperature. As the solubility of calcite is proportional to the CO_2 pressure and the ionic intensity of the solution, the solubility of calcite is higher at lower temperature. Thus high HCO_3 content indicates either high CO_2 pressure or lower temperature.

According to Koga's experiment (1969), sedimentary rocks are more apt to generate more HCO_3 than igneous rocks, and high temperature HCO_3-type water is of sodium bicarbonate ($NaHCO_3$) type ($Na \gg Ca$), and the low temperature HCO_3-rich water is of calcium bicarbonate ($Ca(HCO_3)_2$) type (Ca or Mg > Na). Anyhow, it can be said that more HCO_3 is found in shallow water.

2-2. Steam System

The above mentioned indicators for the hydrothermal system are of no use in the fumarole area not producing hot water. And in the areas considered for geothermal power development, there are unexpectedly many cases of steam system, and it is a pressing problem to establish geochemical indicators in the case of the steam system in the stage of preliminary survey before the deep thermal water is drawn out by boring. As described later, deep thermal water was hardly observed on the surface at Zunil and Moyuta geothermal areas in Guatemala (except at the geyser at Zunil), and the need of establishment of indicators was felt very strongly.

At present, the system of geochemical exploration for the steam system still has much to be clarified, and the present survey team devised and employed the following method. Namely 1) Analyses of furmarole gas: suitable fumaroles must be selected so that the mixing of air can be avoided, and even though gases from all the fumaroles cannot be analyzed, the characteristics of the underground hot water, if any, and the distance from the aquifer can be estimated from the concentrations of gas, CO_2 and H_2S and the CO_2/H_2S ratio in the fumarole gas. 2) Analysis of condensed water from fumarole steam: volatile components are included in the condensed water. For example, NH_3, B, F, etc. are commonly found in the condensed water, and the measurement of Hg in the condensed water has come to be of great interest, because the measurement of Hg can now be made very sensitively (0.0001 ppm). Hg is the element which is most easily vaporized and is affected by temperature most sensitively. Consequently, quantitative analysis of Hg in the fumarole gas might prove to be the best indicator for exploration of high temperature spots underground. Sampling of condensed water is simple, and measurement and comparison of concentrations of such indicators as Hg, NH_3, B, F, etc. in the condensed water, will enable mapping of the high temperature spots in the geothermal area (not necessarily agreeing with the surface phenomena). 3) Quantitative determination of Hg in the altered soil: although Hg is an element easily vaporized by neat, Hg is sedimented in HgS form or adsorbed by temperature drop at the surface in the soil subjected to hydrothermal alteration and/or alteration by steam and in the hot spring sediments, and the concentration of Hg in the altered soil indicates the geothermal structure underground.

The considerations of the geothermal area in Guatemala are made in the following, based on the foregoing geochemical indicators in geothermal development (1. Hydrothermal System and 2. Steam System).

3. Geothermal Areas in Guatemala

As stated before, the survey was started with the pursuit of deep thermal water (high temperature, neutral, salt spring type). As a result, water samples were taken in the areas shaded in Fig. V-1, and the results of analyses are shown on Table V-1. The triangle chart of anions of the hot spring water is shown in Fig. V-2, and it was found that there were only a few samples of deep thermal water, namely those from a few hot springs on the south bank of Lake Amatitlan, Ixpaco and San Marcos and the Geyser in Zunil. The rest of the samples were either Cl-HCO3 water diluted with shallow underground water or steam heated water of low pH, high SO_4 and very little Cl.

Though Guatemala belongs to the Circum-Pacific Volcanic Zone and has some volcanos and abundant water, the high temperature neutral or alkaline salt sping type hot spring with large discharge is found only in the geyser at Zunil, and many hot springs are of higher HCO_3 and SO_4 contents than in other volcanic countries. The rock structure and long distance of the aquiter from the ground surface may be considered as one reason for this, and on the other hand small permeability of rocks is generally suspected. The conditions differ by the type of rocks and similar phenomena are seen when the passages and holes are blocked by SiO_2 or calcite. In such places, the high temperature water of salt spring type from the deep part is limited in flow and is diluted by low Cl water before it reaches the surface. On the other hand, steam is easier to come out on the surface than water and tends to condence and heat the underground water making water of high CHO_3, SO_4 and NH_4 content. The hot spring in Guatemala are considered to be of this type of formation, and such natural hot springs may not necessarily mean that the deep underground aquifers are small.

The compositions of hot spring water in Guatemala are shown in Fig. V-2, and the Cl/B ratio differs by the location as shown in Fig. V-3, even though the hot springs are of the same salt spring type. Fig. V-3 is the Cl-B-HCO_3 triangle chart, and shows that the water from San Marcos and Zunil areas has small Cl/B ratio and large B content, and on the other hand high temperature water from the south bank of Laka Amatitlan has high Cl/B ratios (approx. 30) and small B. The water from Asuncion Mita, Ixpaco and Amatitlan of $HCO_3 > Cl$ are in between. Thus the features of hot springs in the geothermal areas in Guatemala can be seen in Fig. V-2 and V-3.

Table V-1 shows the atomic ratios of the components, and the discussions of indicators for high temperature with hydrothermal systems as described in Section 2 will be made in the sub-sections treating individual hot spring areas.

3-1. Zunil Area

In Zunil Area, 11 samples of hot spring water, 2 samples of water condensed from the fumarole steam, 10 samples of altered soil and 1 sample of steam were collected. Fig. V-4 shows the location of hot springs.

Zunil 1 is located between Zunil and Almolonga along the highway and is a hot spring resortwith many bath tubs, but the source of hot spring is said to be about 500 m away. It is a sodium bicarbonate type simple hot spring of temperature of 45°C. Zunil 2 is called Los Banos (Almolonga) and the temperature is 40°C and is used for bathing. It is located side by side with Zunil 1 across the hyghway, and is a simple hot spring of the same sodiumbicarbonate type. Zunil 3 is located on the bank of River Samala, has 55°C of water temperature and there are several hot springs nearby. They are used for bathing and washing in the form of natural hot spring baths. They also are simple hot springs of sodium bicarbonate type. Zunil 4 is located 1.5 km upstream of the Town of Zunil and there are several hot springs on the bank making a hot spring resort. The temperature of water is 49°C and they are simple hot springs of sodium bicarbonate type. Zunil 5 is located on the highland of 2,450 m and is called "Balneario Fuentes Georginas". There are hot water swimming pools and hotel facilities, and it is an acid hot spring of 50°C of water temperature and pH 2.1. There is a solfatara with deposits of crystalline sulfur and rocks have undergone alteration. The surface temperature is from 70°C to 90°C and the smell of hydrogen sulfide is not very strong. Zunil 6 is a similar acid spring of pH 2.2, and is a hot spring therapy center in the mountain. The hot spring water comes out from fracture lines and green algae grow along the waterways.

The center of Zunil Geothermal Area is the so-called Fumarole Grande where there are many hot springs and fumaroles along the big valley of Rio Semola. Fig. V-5 is the sketch of the vicinity. Zunil 7 is located at the southern end of this group on the right bank and the temperature is 66°C. There are considerable discharges of hot springs nearby and they have caused beautiful yellow, orange, brown and green pallet-like deposits on the cliff on the river. The main component is calcium carbonate. There are many hot springs about 300 m upstream, at the foot of cliffs of 80~100 m height above the river and there are deposit of calcium carbonate. Zunil 8 is one of them and has a temperature of 62°C. 100 m further upstream, the banks close on the river, where the geyser Zunil 9 can be seen from the left bank. The temperature is yet to be measured, but it is at the boiling point and the discharge is large (500 l/mon). White deposit flows down into the river, and just side by side, Zunil 10 with green algae flows into the river like a waterfall.

It is an acid spring of pH 3.2 in contrast to pH 9.0 of Zunil 9. On the right bank, the hot water of Zunil 11 flows into Rio Samola. This is a sodium bicarbonate type spring of pH 8.3.

To summarize the observations of hot springs in Zunil Area, as seen in Table V-1, Zunil 9 is the center and its water is near deep thermal water. The farther from this Zunil 9, the lower the temperature of hot springs and the more the HCO_3 and SO_4 contents. Namely, Zunil 9 is of a salt-spring type with 713 ppm of Cl and contains high SiO_2, H_2S, As, HBO_2, PO_4, F, Li and NH_4, and the low Na/Li ratio and high Ca/Mg, Na/Ca, Cl/HCO_3, Cl/SO_4 ratios satisfy the indicators showing high underground temperature.

It is interesting to note that Mg is high as compared with Ca in the other Hot Springs 7, 8, 10 and 11, and especially Hot Springs 8 and 11 shows the characteristics of Ca > Mg. This is a phenomenon seen in hot springs of high HCO_3 and of not very high temperatures, where the shallow water heated by the secondary steam reacts with the wall rocks and dissolves Ca and Mg. There are probably chlorite and serpentine in the surrounding rocks and the underground temperature is supposed to be 100~120°C at most judging from large amount of sedimentation of flower sulphur.

SiO_2 content is relatively high even in the water of low Cl content and it is supposed that the underground water contains high SiO_2 as usual with the water in volcanic zones. Except for the geyser, the hot spring water in Zunil is all saturated or nearly saturated with amorphous silica at the gushing temperature. Consequently, it is impossible to compute the temperature of the underground aquifer from the SiO_2 concentration, as in the case of the deep thermal water which is considered to be at equilibrium with quartz. Excepting Zunil 9, the underground temperature is estimated to be 110°C or lower.

With Hot Springs 7, 8, 9, 10 and 11 near Fumarole Grande, there is the proportional relationship between the Cl content and the Na/K ratio. Namely, while the smaller the Na/K ratio the higher the temperature and Cl content with deep thermal water, the reverse relationship exists here and this again precludes the application of the Na/K ratio method. As an explanation, if it is assumed that there is thermal water with a high Cl content and a high Na/K ratio (17.9 at Zunil 9), and it is diluted with underground water with a small Cl content and a small Na/K ratio, the spring water will be of a small Cl content and a small Na/K ratio. In other words, if the underground water at Zunil Area is of very small Na/K ratio, for example Na : 10 ppm and k : 10 ppm and almost zero Cl, the foregoing phenomena would easily occur. The low Na/K ratio at Zunil 5, 6 and 10 is because they are acid springs.

As seen in Fig. V-3, the hot springs at Zunil has a feature of a high B content as compared with Cl, similar to the hot springs at adjacent San Marcos, but the values are not consistent, indicating that the rock structure in Zunil Area as a whole is not so simple.

As stated above, the so-called deep thermal water is observed only at the geyser of Zunil 9. The temperature of the underground aquifer computed by the SiO_2 method and the Na/K ratio method is 216°C and 180°C, respectively, and it is estimated at 180°C or over in consideration of the fact that it is a geyser, but with the other hot springs, the indicators for the underground temperature of the hydrothermal system as described in Section 2 do not give favorable results, and are not applicable. Namely, as is clear in the Cl/HCO_3 ratio, the hot spring water except from Zunil 9 is all shallow water.

However, the geothermal potential in Zunil Area is supposed to be considerably large, and the small permeability of the rocks may be the cause of the aforementioned surface phenomena. As an approach to locate the underground high temperature spots stated in Section 2 from the phenomena of fumaroles in Zunil Area, analyses of 1) fumarole gas, 2) condensed water from fumarole steam, and 3) altered clayey minerals were made.

Fumarole are located around Fumarole Grande, Fumarole Negra on the downstream of Pachamiya River, by the road near the hot spring Balneario Fueates Georgina near Zunil 5, solfatara on the north of Volcan de Zunil, near Volcan cerro Quemado, and by the highway near Fumarole Grand. (Fig. V-5) The gas analysis was carried out at Fumarole Negra on the downstream of Pacharmiya River. The results were; temperature was over 94°C (boiling point at this altitude), steam 99.16% and gas concentration 0.84%; with incondensable gases, CO_2 94.2%, H_2S 1.3% and others 4.5%; 10.3 m mol of H_2S and 720 m mol of CO_2 in 100 mol of steam; and the mol ratio of CO_2/H_2S was 70.

The small CO_2/H_2S ratio indicates that either the aquifer is near the surface, or the thermal water is acid; or the thermal water is not existing into deep underground but it is a stream system. And contrarily, a large CO_2/H_2S ratio as in the case of analysis of the fumarole gas in Zunil, indicates that there is neutral or slightly alkaline (not acid) thermal water underground from which the fumaroles originate. (Mahon 1970, Koga and Noda 1973) In fact, the hot spring water of pH 9.0 of salt spring type at Zunil 9 seems to evidence it. On the other hand, too high CO_2 content (high CO_2/H_2S ratio) may cause deposit of calcium carbonate in the pipe line when a geothermal power plant is built.

The samples of condensed water were taken from 2 points in Zunil Area, namely one at Fumarole Negra (same as gas analysis point) and another from the weak fumarole by the highway to the west of Fumarole Grande, in Fig. V-5. The results of analysis are given in Table V-2.

Table V-2. Chemical Analysis of Condensed Water from Fumaroles in Zunil

by Koga (1973)

Location	HBO_2	NH_4	Hg
Fumarole Grande	2.7 ppm	11.0 ppm	0.18 ppm
Road Side	12.2 ppm	6.9 ppm	0.44 ppm

There components are all volatile and are related with the quantities underground. If the steam comes from the same aquifer and is gasified in proportion to the underground temperature, the quantities of these components in the condensed water would indicate the underground temperature. However, it should be noted that in case the steam discharges from the fumaroles are nearly equal, higher HBO_2, NH_4, Hg and Fe contents indicate higher underground temperature, but in a case like this where the Fumarole Grande is a very prominent fumarole while the fumarole on the roadside is very weak, the latter shows higher HBO_3 and Hg contents and appears to have higher underground temperature. But these are the results of dilution by steam, and comparison should be made by the products of the above concentrations multiplied by the total discharge of the fumarolic steam. Even so, the fumarole on the roadside must have a considerably high temperature, though it is weak. This is a good example of cases where the apparent surface phenomena are not direct indications of underground temperature.

The above caution is necessary in the case of condensed water from the fumarolic steam, but direct comparison is possible in the case of altered soild. The results of measurement of Hg in the altered clay in and around Fumarole Negra are shown one Table V-3.

Table V-3. Hg Contents in Altered Clays in Zunil

Analysed by Koga (1973)

Location	Color	Hg ppm	Collector (sample No.)
Fumarole Negra			
1	reddish brown	690	Matsumoto (73131209 a)
2	pale brown	610	" (" b)
3	white	76	" (" c)
4	very pale brown	160	" (73031211)
5	"	33	" (73031215)
6	reddish brown	267	Koga
Balneario Fueates Georgina			
1	medium brown	29	Matsumoto (73031505)
2	white	12	" (73031506)
3	sulfur	1.8	Koga
Sulfur mine	very pale brown	30	Matsumoto (73031502)

The table shows that a large quantity of Hg is condensed in the altered clay in the prominent fumarole zone such as Fumarole Negra. The Hg carried in the fumarolic steam is probably adsorbed in the soil due to condensation by temperature drop near the surface, and it seems to be replemished continuously. The form of the adsorbed Hg is not known, but some part of it is supposed to be in the form of HgS (cinnabar). The altered clay in the extinct solfatara zones which are now cold, contains very little Hs as shown in Table V-3, and the measurement of Hg content in the soil can make an effective indicator of the underground temperature. In Zunil Area, there are some more fumarole areas aside from Fumarole Grande, and the systematic sampling and measurement of Hg in the soil in this area will enable geochemical application in the geothermal development program. It is said that some drug had once been made secratly by ancient Indios at some mercury mines in Zunil, and a large applicability of use of Hg in the geothermal development may be expected. Of course, in case condensed water samples can be collected easily from the fumarolic steam, HBO_2, NH_4, F and Hg contents in the condensed water should be measured. In the present study, however, F content in the condensed water was not measured because of the limited quantities of the samples. How volatile these elementary compounds are according to the temperature will have to wait for more experimental studies with fundamental models.

The quantities of Hg in the hot spring water was measured with 11 samples taken from hot springs in Zunil. The results are given on Fig. V-5, namely 2.8 γ/l at Zunil 1; 1.0 γ/l at 2; 0.8 γ/l at 3; 2.5 γ/l at 4; 1.3 γ/l at 5; 0.9 γ/l at 6; 1.4 γ/l at 7; 1.3 γ/l at 8; 3.3 γ/l at 9; 1.1 γ/l at 10 and 3.9 γ/l at 11. The Hg content is very low in the hot spring water, probably because Hg is so volitile that it is lost immediately after the water springs out. The reason why Hg content is higher at Zunil 9 and 11 inspite of highet temperatures in probably because they are nearer to the aquifer.

3-2. San Marcos Area

San Marcos is located about 50 km to the west of Quezaltenango, and there are a few geothermal area to the south of the Town of San Marcos. (Fig. V-1)

SM-1 springs out from the cliff by the road near the tunnerl, and is of a weak salt spring type with a temperature of 88°C. SM-2 springs out in a cave near temperature is 77°C. The river flows over the road and flows down in a fall of 10 m drop, and there is a cave-like depression on the back of the fall where there spring out many hot springs and the floor makes a terrace of calcium carbonate. The hot springs are also of weak salt spring type. SM-3 is locat d about 1 km to the south of SM-2 and springs out in a valley about 100 m below the road among many other hot springs and mud pools. The temperature is 87°C and the spring is also of weak salt spring type.

The hot springs in San Marcos are of weak alkaline salt spring type as seen in Table V-1 and Fig. V-2, and they have a feature of very high HBO_2 content like hot springs in Zunil, as seen in Fig. V-3. And the fact that the 3 hot springs have the same value of Cl/B ratio, namely 7.4, shows that they come from the same aquifer. The hot spring water in San Marcos has such indications showing high underground temperature as the high SiO_2 content, high Li and consequently low Na/Li ratio, high Na/Ca and Ca/Mg ratios, relatively high Cl-HCO_3 ratio, and high As content, and especially high temperature is observed in SM-3, where the temperature computed by Na/K ratio and SiO_2 content shows 220 - 230°C and the As content is 6.44 ppm. In the cave of SM-2, there is also fumarolic steam rising, and 65.2 ppm of Hg supposed to be carried by the steam was found in the deposit. SM-3 may be the conter, but the underground part of SM-2 is supposed to be a considerably high temperature.

To summarize, the chemical analysis indicates that there is a high temperature aquifer in the San Marcos Area, even though the scale may not be so great, and the Area may be a promising one for geothermal development.

3-3. Envirous of Lake Amatitlan

There are many salt hot springs of 70 - 80°C on the south bank of Lake Amatitlan. A-1 in Table V-1 is located in the Trailer Park on the road to Escuintla and the hot spring has a temperature of 56°C and is used for hot spring pools. A-2 has a temperature of 72°C. They are both bored hot springs and of sodium carbonate spring type. Their visinity is a marsh land where once were natural hot springs. A-3 is located at Hotel Los Arcos at the west end of the lake, from where the only river Michatoya flows out, and is of a weak salt spring type of 58°C of temperature. A-4 springs out in the sand near the station on the south bank of the lake. The temperature of the hot spring is 70°C and the hot spring is of salt spring type. A-5, called "chicken pool", is located about 400m to the west of A-4. Though the discharge is small, the temperature is 79°C and it has 1,180 ppm of Cl content, the highest value among hot springs in Guatemala.

The hot springs on the south bank of Lake Amatitlan are considered to come from the same aquifer as seen on Fig. VI-3, have high Cl/B ratios of over 30, and are featured by small B content among hot springs in Guatemala. The Fe and As contents also are lower than the hot springs in other districts. The underground temperature is computed, from the SiO_2 concentration and Na/K ratio of A-5 having high Cl/HCO_3 ratio, to be 198°C and 206°C respectively, indicating the existence of thermal water of approximately 200°C under the ground.

3-4. Ixpaco Area

Ixpaco is located in the mountain to the south of the Moyuta Highway. (Fig. V-1) Ixpaco 1 is a pond of about 800 m diameter and has yellowish water color due to sulphur. The smell of H_2S or SO_2 is felt and it is extremely acid with a pH value of 1.6 due to sulphuric acid. Ixpaco 2 is the spring on the pond and is a hot spring heated by fumarolic steam. Therefore, it lacks Cl and contains high NH_4. Its higher F content than the pond water seems to be due to the fumarolic steam. Ixpaco 3 and 4 spring out in the El Panal River on the highway side of the pond. The temperature is approximately 90°C, and the discharge is large, with red, green and brown colored deposits and also deposit of salt. At the first glance it seemed to be a promising deep thermal water, but the Na/K ratio is high and SiO_2 is disappointingly low and the underground temperature does not seem to be high.

3-5. Asuncion Mita Area

This is a hot spring located near El Salvador border. The temperature of hot spring is 70°C, and the spring mouth is elevated in a dome shape, from which the spring water flows down leaving deposits in red, orange and green stripes. The water springs out in white foam due to CO_2 and it appeas as if it were boiling. The spring is of sodium bicarbonate type including salt, and hot underground temperature cannot be expected in view of the SiO_2 content.

3-6. El Coco

A considerably quantity of water springs out in a bat-inhabited cave on the Moyuta Highway near El Salvador border. It is a clear simple spring water of 29°C, but people do not dare to drink it from fear.

3-7. Moyuta Area

Surveys had been made in Moyuta Area by the United Nations, INDE and the Mining Bureau, and chemically, the temperatures and HCO_3 contents of water from various hot springs and cold springs, and gas components of steam from several fumarole had been measured.

Nine high temperature hot spring water samples were taken from this area, namely 2 samples from Guinea, 4 from Marcuccy, and 3 from Azulco. Moyuta 1, 2, 3 and 4 are all located in Marcuccy at about 20 minutes on foot from Guinea, and are boiling up right near a not too active fumarole zone in the dry season. The discharge is almost zero and it appears that the surface water is heated by the fumarolic steam. Moyuta 1 and 4 are neutral, while Moyuta 2 and 3 are acid, and there was observed small deposits of red clay similar to that at "CHINOIKE JIGOKU" (Red Blood Pond) in Beppu, Japan. They are featured by very little Cl and high Ca contents. Moyuta 5 and 6 are hot springs located in a river in Guinea. Both have a temperature of approximately 90°C and are water heated by the fumarolic stream. Both of them are acid, but Moyuta 5 has a high NH_4 content while Moyuta 6 has a low NH_4 content.

Azulco is located about 7 km north-northeast from Moyuta, and here is a large fumarole with not springs nearby. Moyuta 7, 8 and 9 are all steam heated water and are alkaline. Surveys had been made by the Ministry of Mines with water from hot springs and cold springs in Moyuta Area and the water temperature and NCO_3 were measured. And it is seen that there are springs with high HCO_3 content in Azulco Area.

The hot spring water in Moyuta Area has also a high SiO_2 content, but it is not saturated as against amorphous silica, probably because of short reaction time.

On the other hand, surveys of fumarolic gas in the Moyuta Geothermal Area had been made by Cuellar (1972), by which the fumarolic gas from Guinea has high CO_2 and H_2S content but that from Azulco has low CO_2 and H_2S content. The fumarolic gas from Marcuccy shows the values in between, and the CO_2/H_2S ratio is around 100～140, which is high as compared with 70 in Zunil obtained by the present survey. And if there is an aquifer under the ground, (even though there is not flow-out on the surface), it would be a weak alkaline salt spring.

The results of analysis of condensed water from fumarolic steam in the Marcuccy Area are given in Table V-4.

Table V-4. Chemical Analysis of Condensed Water from Fumaroles in Moyuta Analyzed by Koga (1973)

Location	HBO_2	NH_4	Hg
Marcuccy	3.4 ppm	4.8 ppm	0.20 ppm
Guinea ①	5.6 ppm	27.2 ppm	0.41 ppm
②	2.2 ppm	7.2 ppm	0.14 ppm

Guinea is more active with larger fumarolic discharge than Marcuccy. Guinea 1 and 2 are located at the same places as Moyuta 5 and t of hot springs, and the fact that the hot spring water from Moyuta 5 contains higher HBO_2 and NH_4 as with the condensed water from the fumarolic steam, suggests that the hot spring water is a steam heated water by the fumarolic gas.

Hg of 27.0 ppm and 4.8 ppm was measured in the read soil near the fumarole in Azulco and in the red-brown soil on top of the altered dome (90～95°C), respectively. These values are not high as compared with that in Zunil Area, but the fact that the condensed water from the fumarolic gas contains high Hg, seems to indicated a high underground temperature at Moyuta as in Zunil Area.

Since no occurrence on the surface of deep thermal water is found in Moyuta Area, the geochemical survey for geothermal development should center on the analysis of the fumarolic gas and condensed water from the fumarolic steam, and the measurement of Hg in the altered soil. It is expected that promising results would be obtained.

3-8. Ahuachapan

There are 12 production wells now under drilling at Ahuachapan in El Salvador and geochemical study of the area had been made by Sigvaldson and Cuellar (1970). There once were a huge solfatara and fumarole zone nearby and the water taken there is entered as Ahuachapan 2 on Table V-1. It is stream heated water. There are many analysis data with the water from Production Well No. 1, and it is a strong salt spring and the underground temperature is reported as 228°C. In the results of the analyses of the sample taken in the present survey, the biggest discrepancy is seen in the iodine content. While the former analysis gave Br 42.1 ppm and I 8.46 ppm, the present analysis resulted in Br 34.4 ppm and I 0.246 ppm. The origin of this water of high salt concentration is of great interest, and according to the former data marine sediment was conveniently suspected from the high I content, but non-existence of marine sediment has been confirmed by the boring core. Consequently, the measurement of iodine by the present analysis is believed to be correct, and the origin of the salt is yet to be found out.

Table V-1 Chemical Compositions of hot spring waters in Guatemala and El Salvador (PPM) Analysed by Koga and Noda (1973)

No.	Location	Date	T °c	pH	K	Na	Li	NH_4	Ca	Mg	Cl	SO_4	HCO_3	F	PO_4	HBO_2	SiO_2	CO_2	H_2S	As	Na/K	Na/Li	Na/Ca	Ca/Mg	Cl/F	Cl/HCO_3	Cl/SO_4	Cl/B	$X10^3$ Cl/As
1	Zunil 1	12/3/73	45	7.2	6	93	0.20	0.3	21	7.0	71	50	150	0.32	0.39	6.8	164	-	0.5	0.04	26.7	140	3.8	2.1	120	0.8	2.0	12.9	4.0
2	2	"	40	6.6	9	86	0.15	0.3	22	9.9	56	29	257	0.19	0.63	3.8	197	-	0.5	0.01	16.1	170	3.4	1.4	160	0.4	2.7	18.2	16.0
3	3	"	55	7.2	15	102	0.25	0.4	15	7.2	82	37	198	0.29	0.57	9.7	195	-	0.7	0.40	11.6	120	5.9	1.3	155	0.7	2.9	10.5	0.4
4	4	"	49	7.4	10	64	0.16	0.3	14	5.2	60	25	148	0.22	0.47	6.7	159	-	0.7	0.04	10.8	120	4.0	1.6	140	0.7	3.4	11.1	3.4
5	5	"	50	2.1	26	72	0.04	0.3	31	12.6	28	520	0	0.10	0.43	11.6	250	0	0.7	0.02	4.7	520	2.0	1.4	160	-	0.1	3.0	2.7
6	6	"	55	2.2	34	96	0.07	0.5	41	23.0	18	460	0	0.00	0.43	4.7	218	0	0.7	0.01	4.8	420	2.0	1.1	-	-	0.1	4.8	5.0
7	7	13/3/73	66	7.2	30	176	0.60	0.4	38	35.7	167	120	402	0.28	1.31	21.0	227	-	0.7	0.20	10.0	90	4.1	0.6	315	0.7	1.9	9.9	1.7
8	8	"	62	7.3	38	265	0.54	0.3	41	52.2	199	110	681	0.35	0.75	24.5	225	-	0.5	0.14	11.9	150	5.6	0.5	310	0.5	2.4	10.0	2.9
9	9	14/3/73	n.d.	9.0	53	558	2.60	0.8	11	2.1	713	185	129	3.4	2.67	107	439	0	1.7	1.38	17.9	60	44.2	3.2	110	9.5	5.2	8.3	1.1
10	10	"	n.d.	3.2	25	105	0.71	0.3	37	19.5	21	310	0	0.10	0.36	3.7	224	0	0.6	0.06	7.2	50	2.5	1.2	120	-	0.1	7.0	0.8
11	11	"	n.d.	8.3	36	319	0.56	0.4	30	46.9	201	135	595	0.30	0.54	28.5	224	0	0.6	0.12	15.1	170	9.3	0.4	380	0.6	2.0	8.7	3.6
12	Amatitlan 1	15/3/73	56	7.3	40	256	0.42	0.2	31	20.6	185	58	545	0.29	0.46	11.4	228	-	-	0.07	10.9	180	7.2	0.9	360	0.6	4.3	20.7	5.8
13	2	"	72	7.0	33	246	0.43	0.3	32	25.7	171	52	548	0.32	0.57	12.3	206	-	-	0.48	12.7	170	6.7	0.8	280	0.5	4.4	17.3	0.8
14	3	"	58	8.3	48	502	1.53	0.2	16	2.2	684	48	170	0.55	0.62	28.0	186	0	-	0.12	17.7	100	27.3	4.4	665	4.0	19.3	30.2	12.1
15	4	"	70	6.9	34	254	0.87	0.1	37	17.2	334	55	307	0.15	0.57	12.3	261	-	-	0.04	12.6	90	5.9	1.3	1180	1.9	8.5	33.7	18.8
16	5	"	79	7.0	88	717	2.54	0.2	57	10.1	1180	37	175	0.34	0.93	46.9	262	-	-	0.20	13.9	90	11.0	3.4	1850	11.6	41.6	31.2	12.3
17	El Coco	5/3/73	29	7.3	3	16	0.01	n.d.	18	10.3	14	0.5	132	0.09	0.12	0.5	105	-	0.5	0.01	8.8	700	0.8	1.1	80	0.2	-	40.0	4.0
18	Auhachapan 1	7/3/73	n.d.	6.4	1178	5380	14.5	n.d.	575	2.0	10584	55	49	1.10	7.5	197	486	-	-	3.11	7.8	110	8.2	179	5150	373	271	66.3	7.2
19	2	"	n.d.	6.8	4	16	0.01	n.d.	32	10.9	6	66	110	0.08	0.50	0.2	108	-	-	0.16	7.0	700	0.4	1.8	50	0.1	0.1	-	0.1
20	San Marcos 1	14/3/73	88	7.9	26	482	4.14	0.2	19	2.8	572	128	238	2.38	4.65	95.6	203	-	1.5	2.13	31.5	40	22.1	4.1	130	4.2	6.0	7.4	0.6
21	2	"	77	8.8	39	555	4.57	0.2	8	1.2	685	175	281	3.1	4.05	115	353	0	1.6	1.30	24.1	40	60.3	4.0	120	4.2	5.4	7.4	1.1
22	3	"	87	8.9	75	558	5.91	0.2	8	1.0	745	265	133	3.2	3.81	124	549	0	1.6	6.44	12.6	30	60.8	5.0	130	9.7	3.8	7.4	0.2
23	Ixpaco 1	16/3/73	20	1.6	16	9	0.02	5.0	15	36.2	14	6300	0	0.03	0.18	0.8	162	0	-	0.01	1.0	130	0.5	0.3	50	-	0.0	20.0	4.0
24	2	"	84	1.7	13	11	0.02	4.0	15	36.4	14	6200	0	0.40	0.15	0.6	219	0	-	0.05	1.5	170	0.7	0.2	20	-	0.0	40.0	0.6
25	3	"	87	7.2	26	626	1.70	0.2	52	3.1	810	307	128	1.5	2.2	83.7	105	-	-	0.67	41.2	110	10.5	1.0	290	10.9	3.6	11.9	2.6
26	4	"	91	7.1	25	623	1.71	0.2	54	2.4	720	427	124	1.6	0.0	75.4	108	-	-	0.41	42.3	110	10.1	1.3	240	10.2	2.4	11.8	3.7
27	Asuncion Mita	17/3/73	70	6.8	117	743	3.06	0.2	41	13.0	643	44	1110	0.36	0.41	47.8	104	690	-	1.73	10.8	70	15.8	1.9	950	1.0	20.1	16.6	0.8
28	Moyuta 1	19/3/73	90	7.0	12	28	0.01	0.3	66	10.9	18	156	73	0.05	0.11	1.4	134	-	-	0.00	3.9	1200	0.4	3.7	170	0.4	0.1	16.7	-
29	2	"	89	3.5	12	36	0.00	4.5	43	21.0	18	700	0	0.13	0.24	0.2	183	0	-	0.00	5.2	-	0.7	1.2	70	-	0.0	-	-
30	3	"	92	3.8	11	25	0.00	0.9	155	10.7	14	500	0	0.07	0.19	0.9	138	0	-	0.00	3.9	-	0.1	8.8	100	-	0.0	20.0	-
31	4	"	89	6.6	9	25	0.00	0.2	72	12.4	14	154	46	0.11	0.51	0.8	164	-	-	0.00	4.8	-	0.3	3.5	70	0.5	0.1	20.0	-
32	5	"	89	2.3	7	27	0.01	4.0	39	21.7	14	2100	0	0.07	0.16	1.7	335	0	-	0.00	6.7	1200	0.6	1.1	100	-	0.0	10.0	-
33	6	"	90	3.2	7	16	0.01	0.3	35	13.7	14	220	0	0.36	0.22	0.5	209	0	-	0.00	3.9	700	0.4	1.5	20	-	0.1	40.0	-
34	7	"	93	8.9	3	11	0.00	0.3	9	1.3	14	27	30	0.03	0.16	0.0	143	0	-	0.01	6.3	-	1.1	4.1	200	0.8	0.7	-	4.0
35	8	"	93	8.8	3	9	0.00	0.3	10	1.1	14	27	30	0.03	0.16	0.0	140	0	-	0.00	5.0	-	0.8	5.6	200	0.8	0.7	-	-
36	9	"	93	8.8	3	11	0.00	0.3	9	1.1	14	27	30	0.03	0.16	0.0	141	0	-	0.01	6.3	-	1.1	5.0	200	0.8	0.7	-	4.0

Fig. V－1 DISTRIBUTION OF HOT SPRINGS IN GUATEMALA

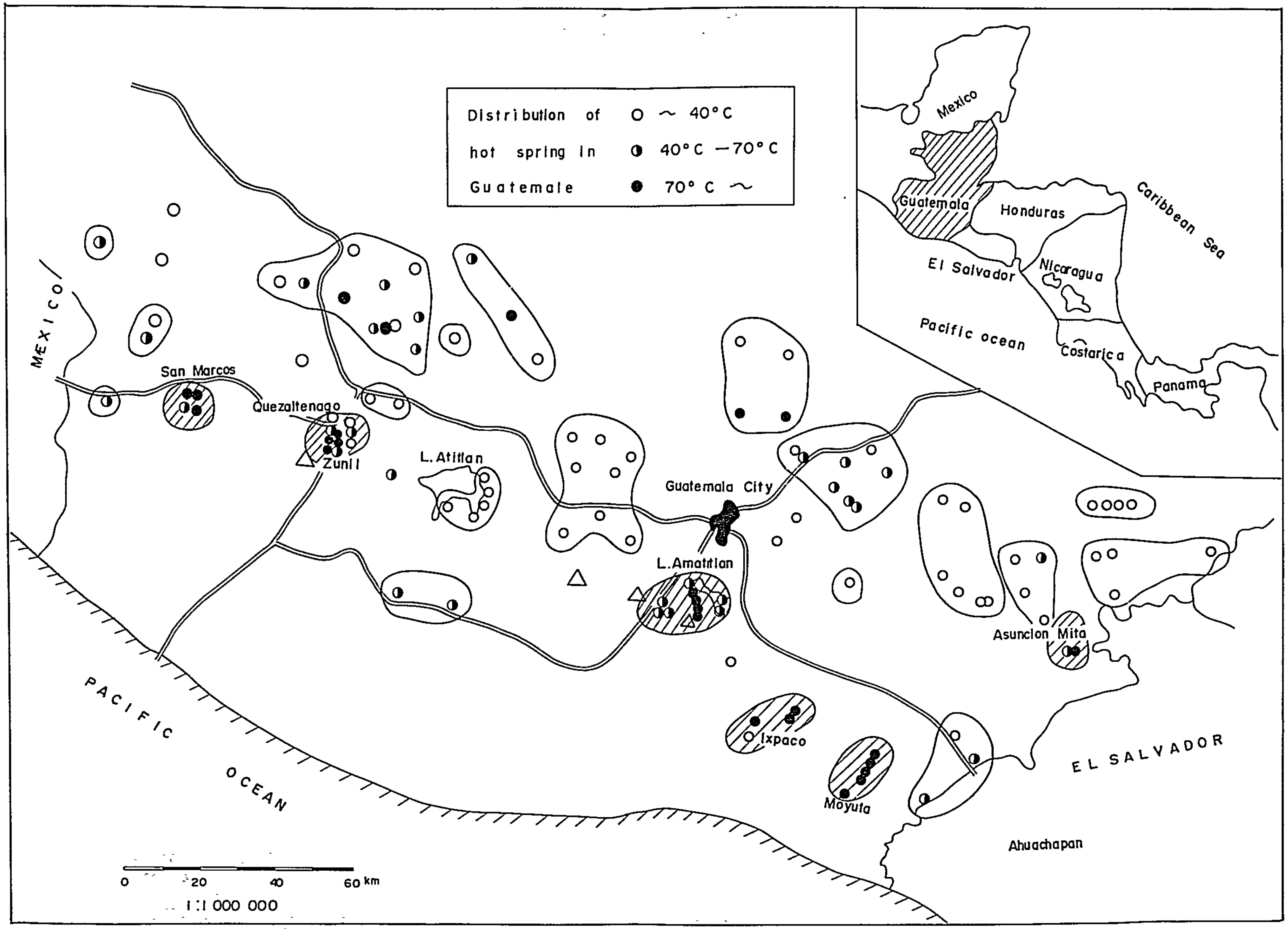


Fig. V – 2 PROPORTIONS OF CL, SO_4, AND HCO_3 IN WATERS OF VARIOUS HYDROTHERMAL AREAS GUATEMALA

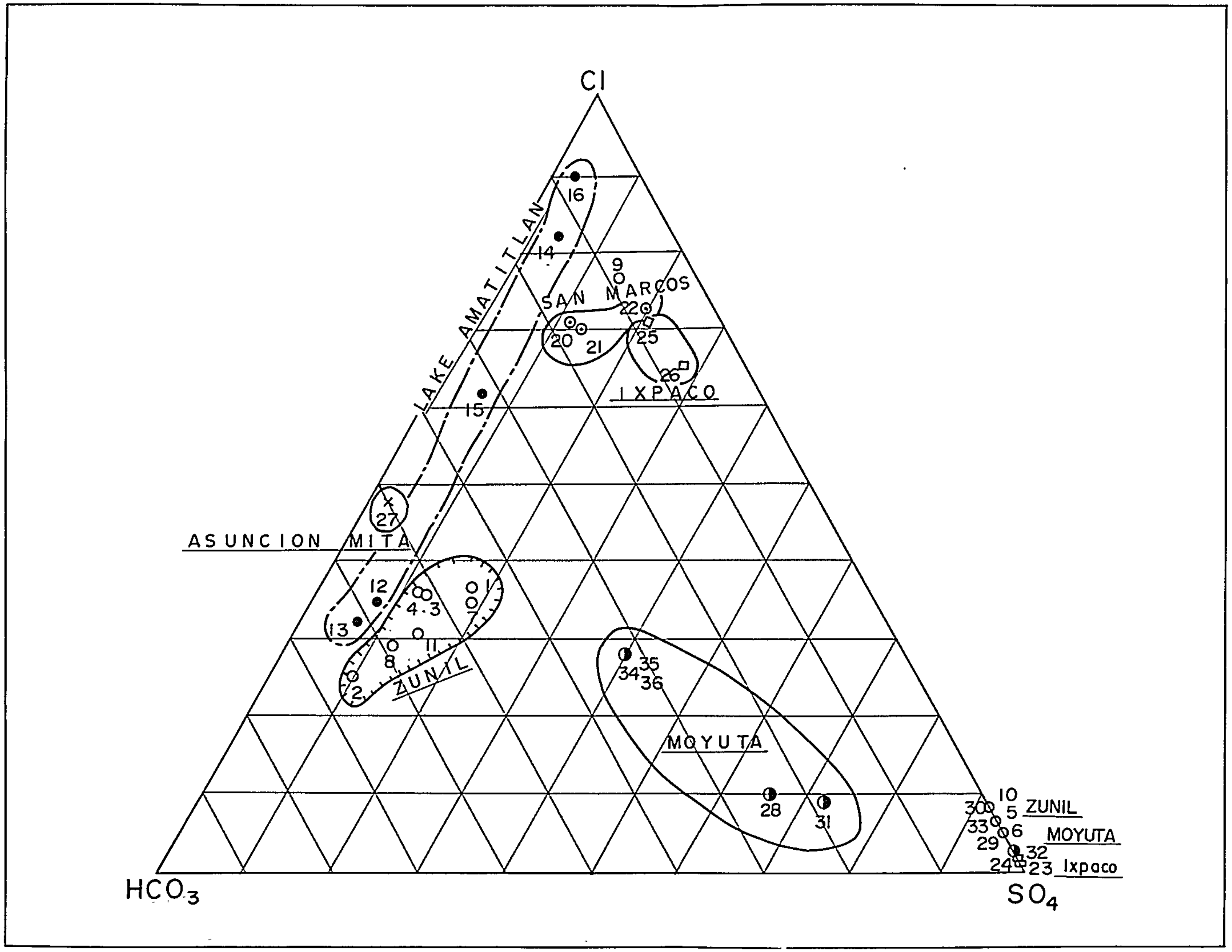


Fig. V-3 MOLECULAR PROPORTIONS OF Cl, B, AND HCO_3 IN WATERS OF VARIOUS HYDROTHERMAI AREAS OF GUATEMAIA

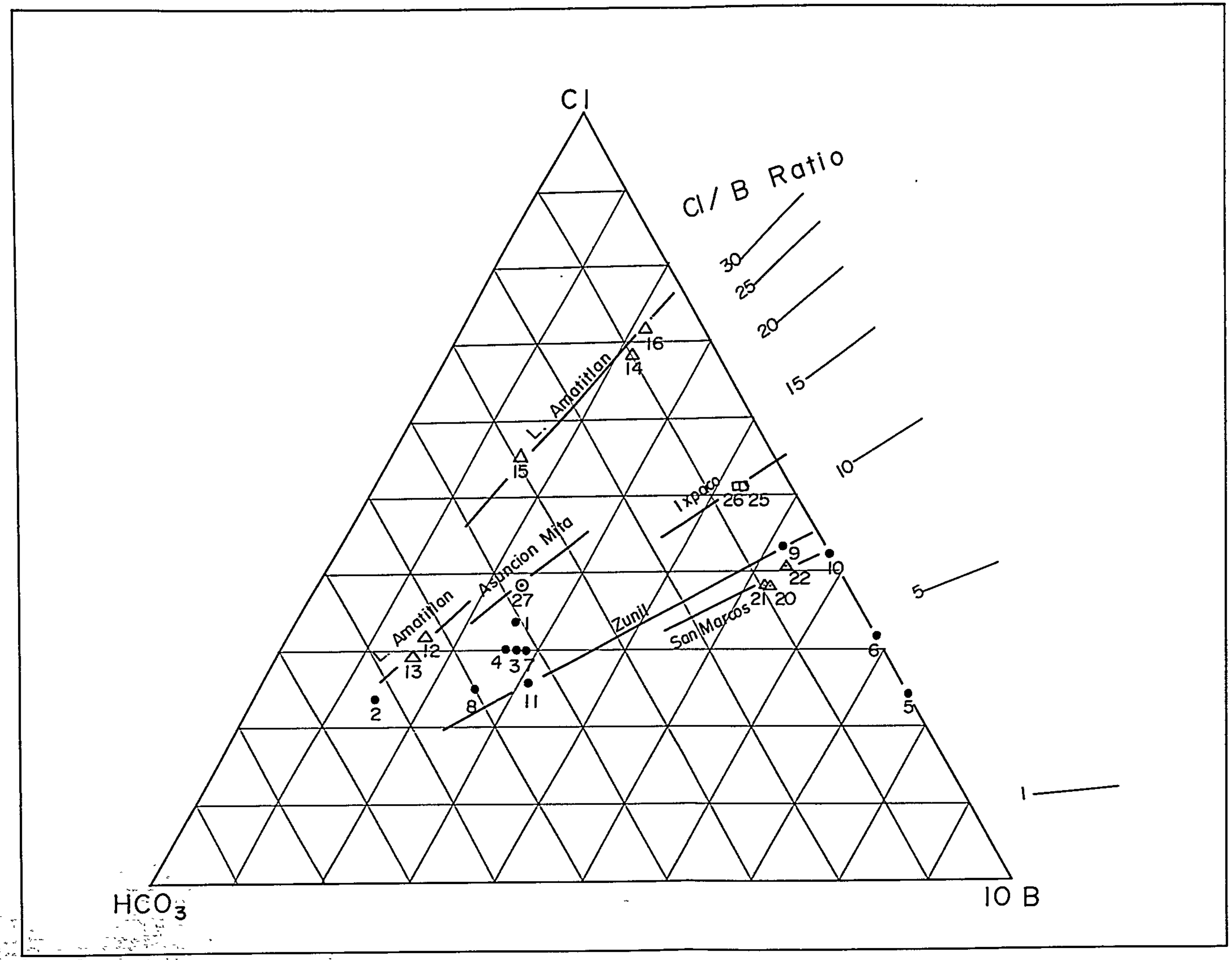


Fig. V – 4 LOCATION MAP OF HOT SPRINGS IN ZUNIL

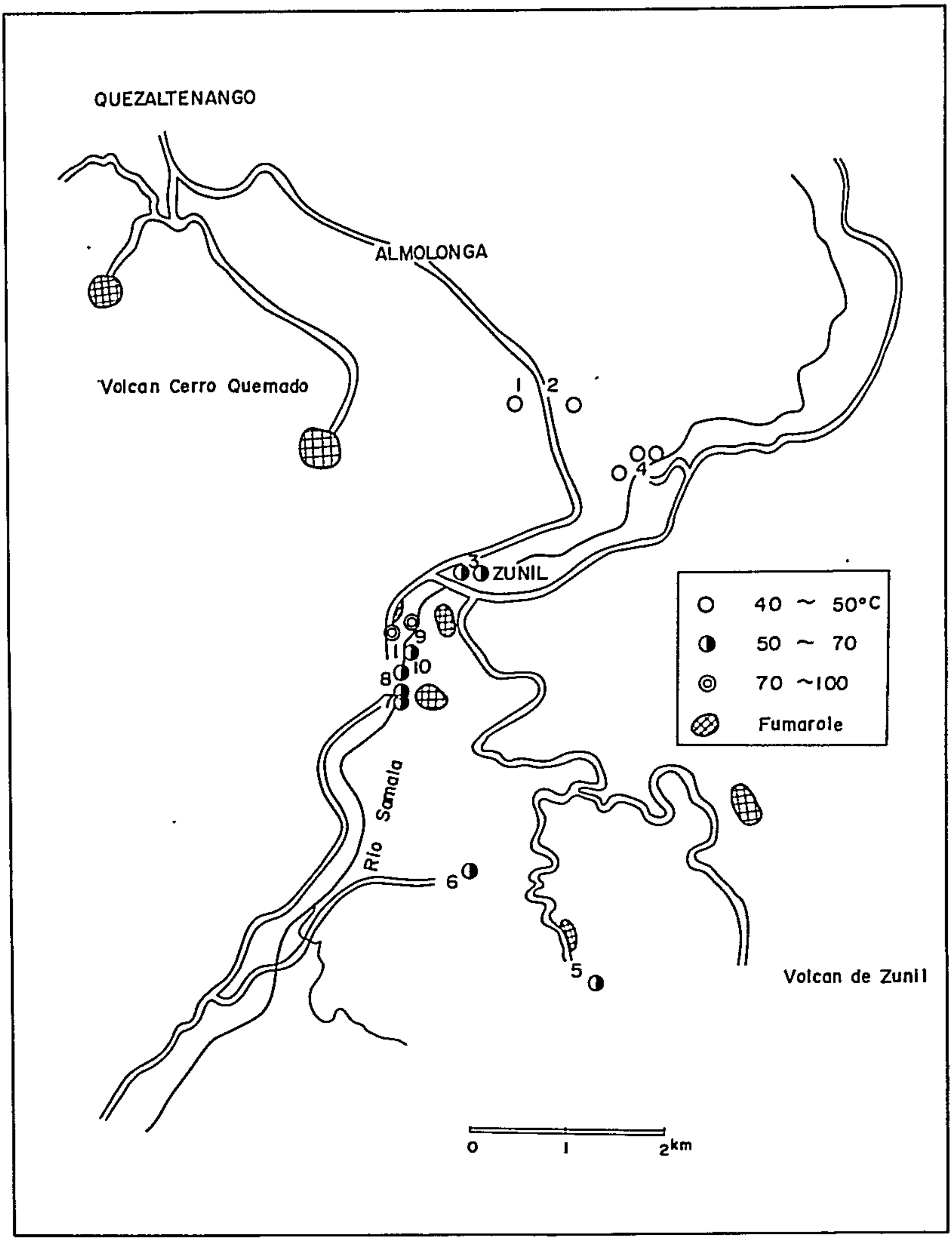
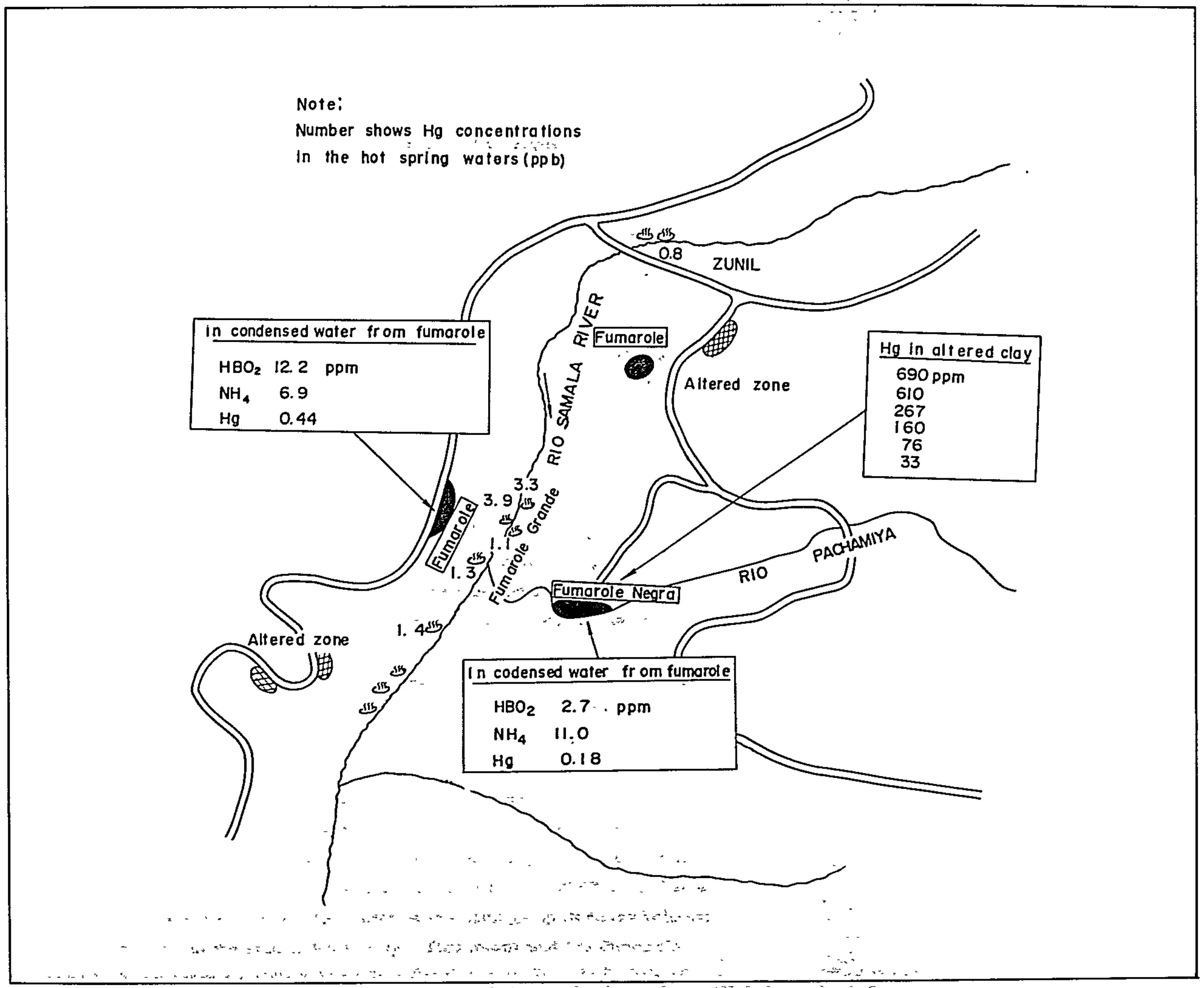


Fig. V − 5 SKETCH MAP OF "FUMAROLE GRANDE" IN ZUNIL



CHAPTER VI GEOTHERMAL ACTIVITIES AND STATUS OF DEVELOPMENT

1. Zunil Geothermal Area

The Zunil Geothermal Area, where R. Raudment of DGMH has recently conducted a preliminary survey, includes the section extending from the south of Quezaltenango City to Zunil village and further south to the Fuente Georgias Hot-spring, with a wide distribution of more than 10 hot-springs and fumaroles (Figs. VI-1 and V-4). The survey conducted by this mission aimed primarily at selecting a site for development from among these areas with geothermal manifestations.

Most of the areas with geothermal manifesations have sporadic hot-springs and fumaroles and the water from them generally has a low temperature. Characteristics of these hot-springs and fumaroles revealed by chemical study have already been described in the preceeding Chapter V. Of these areas, the area to the south of Zunil village including the Fumarole Grande with geysers at the bottom of the gorge of the Samala River and the Fumarole Negra on the east side has a group of active fumaroles and hot-springs, which are believed to make the same geothermal system. Geothermal activities in this area are outstanding and the emphasis of the survey was placed on this area as the most promising area for development. The following is a summary of geothermal activities mainly in this area.

The area is topographically divided into two sections by the Samala River which forms a deep gorge downstream of the Zunil Falls and runs through the center of the area from north to south. Geologically also the area is divided roughly into two sections, the left bank section and the right bank section, by a fault dipping west (the throw roughly estimated at about 100 m) and striking in northwest on the left bank close to the Samala River almost in parallel with the river course.

The outline of geology in this area is as follows. (See Chapter IV, Section 2)

(1) The left bank section (strictly speaking, the section east of NE-fault) has a distribution of the lower ~ lowest formation of the Zunil group (tertiary volcanic rocks) outcropping in the area under survey. This means that the Fumarole Negra which has outcrops of the lowest formation in a small range is the clos-

est to the basement granite. The lower limit of the Zunil group is not known and the determination of the thickness and stratigraphy of the layer between this this lowest formation and the basement granite will be the primary object of the next survey. The Zunil group which is an almost horizontal stratum often forms relatively flat hills and tablelands.

(2) In the right bank section, there are outcrops mainly of middle formation of the Zunil group and the basement is deeper than in the left bank section. In this respect, the right bank section is more favorable as a geothermal field.

The Zunil group on the right bank is covered with very recent Zunil waterfall lava (probably the eruptions in the historical age, belonging to Quaternary volcanic rocks and Cerro Quemado lavas) of an estimated thickness of 100 - 150 m. This lava flow from the southeast foot of Volcano Quemado toward east to the Samala River forming a relatively large fan-shaped plateau, passing the Zunil Falls and covering part of the left bank section in the northern part of this area and forming a bluff on the right bank of the deep gorge of Fumarole Grande in the southern part. From the appearance of this lava, it is evident that the flow of the Samala River was stopped by this lava flow with the resultant creation of a lake in the present Zunil village upstream of the Zunil Falls. Since then, the violent erosion by the Samala River is believed to have created the Zunil Falls and cut the narrow gorge in the lower reaches.

(3) The intrusive rhyodacite forms two domes along the north-east fault. One is relatively large dome on the east side of the Zunil Falls and forms a bluff on the left bank of the Samala River, on the slope of which is observed the Paxmux Fumarole. The other is a small dome separating the Fumarole Grande from the Fumarole Negra and similarly forms a bluff on the left bank of the Samala River with geysers at the bottom of the gorge.

Under the influence of such a topography and geology, this area, divided by the Samala River into the right bank featured by the outstanding Quaternary lava plateau and the left bank featured by the notable Tertiary volcanic rocks, seems to form a striking contrast of topography and geology between the two sections. However, geothermal activities are distributed widely on both banks and as a whole this area constitutes a single geothermal system.

1-1. Distribution of Fumaroles, Hot-springs and Altered Zones

The so-called geothermal manifestations generally include fumaroles, hot-springs and altered rocks resulting from hydro-thermal alteration, and these geothermal manifestations normally distributed with a certain directivity. To determine this characteristic of distribution, the geothermal manifestations were plotted on a sketch map of 1/10,000 scale, prepared at the site.

Back in Japan, the 1/50,000 topographical map, furnished by INDE was photographically enlarged to a scale of 1/10,000 and the geothermal manifestations were transferred to this enlarged topographical map as shown in Fig. VI-1. As is evident from the map, the geothermal manifestations on the surface show three bands of altered zones across the Samala River striking roughly NW-SE. The altered zones referred to herein mean outstanding bands of geothermal manifestations in a certain direction including fumaroles and hot-springs. The fact that the altered zones have a certain directivity has also been pointed out frequently with geothermal zones in various parts of Japan. This is probably an indication of the fact that the present geothermal fields have been formed along the lines of weak geological structure and that the sign of such geothermal activities has reached the ground surface or near the surface.

For convenience's sake, these altered zones will be tentatively named as Altered Zones I, II and III starting from the east and the geothermal manifestations in each altered zone will be outlined in the following. The altered minerals in each zone have already been described in Chapter IV, Section 3. The Altered Zones I, II and III referred to here correspond to the Paxmux District, the northern section and the southern section of the Fumarole Grande-Negra District mentioned in Chapter IV. The geochemical characteristics of the Hot-springs, fumarolic gases, condensed water of fumarolic steam and altered rocks (soils) in each of these zones have already been described in Chapter V.

1-1-1. Altered Zone I (Paxmux Field)

On the right bank of the Samala River, only a weak alteration of lava is observed along the highway traversing the lava plateau.

Also on the right bank of the river, outstanding altered rocks are observed for a distance of about 0.5 km from the entrance to the mountain road (unpaved motor-road) which links Zunil village with the Fuentes Geoginas Hot-spring and the Sulphur Mine. This is on the west slope of the previously mentioned rhyodacite dome and this cliff extends from the road to the bottom of the left bank immediately below the Zunil Falls. At the middle of this cliff, two fumaroles accompanied by altered zones are observed with hot-springs at the bottoms. The joint developed in rhyodacite has a strike of N20-40°W and a small fault (approximately 30 m throw running immediate downstream of the falls has a strike of N65°E, and may be considered to be a secondary fault branching off from the previously mentioned main fault running northeast.

In short, the altered zone in the Paxmux District generally appears to extend in NW direction, and this is probably due to the fact that the area of geothermal manifestations is the result of a combination of fissures caused by the intrusion of highly viscous rhyodacite, the effect of the main NE fault, etc.

1-1-2. Altered Zone II (Northern Section of Fumarole Grande-Negra Field)

Fumarolic activities, though weak in intensity, are noted along the previously mentioned highway traversing the lava plateau on the right bank and the temperature registered there was 71°C. However, the value of Hg in the water condensed from fumarolic steam suggests the existence of a considerably high temperature zone under the ground. The lava around this fumarole also indicates weak alteration.

On the left bank, meanwhile, an altered zone 20 ~ 40 m wide and approximately 180 m in length has developed in the lower reaches of the Pachamiya River, a tributary of the Samala River, where the fumarole is very active at several locations. This fumarole is called the Fumarole Negra. Although the pressure is not so high, the temperature exceeds 94°C (the boiling point at an altitude of about 2,000 m). Deposit of native sulphur at the mouth of the fumarole and large amount of Hg measured suggest the existence of an dominant thermal source under the ground (Chapter V, Section 3-1).

The section of the Pachamiya River meeting the Samala River forms a precipice, thereby developing a waterfall there and its relation with the main course of the Samala River is that of the so-called hanging valley from this confluence of the two rivers to a distance of about 300 m along the Samala River, there are the most conspicuous geothermal manifestations in the area. This is the Fumarole Grande which has a geyser in the precipice on the left bank at a height of about 20 m from the level of river water. The geyser has abundant flow of about 500 l/min and is the only deep hydrothermal system of the saline hot-spring type discovered in the Zunil Geothermal Area, as mentioned previously (Chapter V, Section 3-1). This is an indication of the formation of a geothermal zone of the hydrothermal type with an outstanding reservoir under the ground. In addition, a large amount of high temperature hot-spring water is flushing out in the river bed immediately below the old railroad tracks on the opposite bank of this geyser, and hot-springs of a little lower temperatures flow out along the shoulder of the track bed in the downstream area and at various points on both banks of the Samala River.

Geothermal activities observed on the ground surface are most active in this

Altered Zone II. There are frequently observed silicified rocks containing quartz and cristobalite showing strong alteration, and this is a very promising area. (Chapter IV, Section 3).

After all, Altered Zone II comprises mainly the Fumarole Grande and the Fumarole Negra located on both sides of a small rhyodacite dome, and maintains dynamic geothermal activities with the main NE fault and the fissure system under the influence of this dome playing the role of the passage. The geothermal fluid supplied through this passage is believed to be impounded in the Zunil group and other reservoirs.

1-1-3, Altered Zone III (Southern Section of Fumarole Grande- Field)

Going southward along the highway traversing the lava plateau on the right bank and entering the area of middle formation of the Zunil group covered with this plateau, one finds outstanding altered zones frequently containing the previously mentioned silicified rocks in such locations as the cutting of roads and bluffs of streams. However, no active geothermal manifestations such as fumaroles are observed.

On the other hand, hot-springs are observed at several locations downstream of the previously mentioned Fumarole Grande where the extension of this altered zone nearly crosses the Samala River. This hot-spring water has a temperature range of 60°C - 70°C in most cases and often shows a deposit of travartine at the spring mouths.

1-2. Relationship between Fumarole Activities and Hot-springs

As mentioned previously, the Zunil Geothermal Area shows such geothermal activities as fumaroles and hot-springs accompanied locally by comparatively conspicuous altered rocks. However, altered zones are not always accompanied by such geothermal manifestations as fumaroles and hot-springs. For example, the altered zone along the road running from Zunil to the Georginas Hot-spring (Altered Zone I) or the outstanding altered zone along the highway to the south of the lava plateau (Altered Zone III) is now dormant, but shows clearly a sign of the past fumarole and hot-spring activities on or near the present ground surface. The reason for the pause of geothermal activities may be either (1) the ceasing of fumarolic and hot-spring activities or (2) inadequate potential of thermal water to reach the ground surface.

The question is how to distinguish between the altered zone or the geothermal zone which was formerly active but has completely ceased it activities and the geothermal zone which, despite its lowered potential, still continues its activities and is alive under the ground. This is one of the most important questions common to all nations that must be solved for geothermal development. In other words, the important thing is to reconstruct the history of geothermal activities in each geothermal zone, but it is a very difficult task indeed.

In this particular area, activities of the Fumarole Grande and the Fumarole Negra or minor fumarolic activities in the lava plateau are all considered to reflect the dynamic geothermal activities under the ground as previously mentioned, and it is not appropriate to conclude that geothermal activities in this area have ceased to function.

Apart from the question of whether the geothermal activities are becoming weaker gradually, the following reason, though it may seem very simple, is conceivable for the failure of fumarolic gas or thermal water to reach directly the altered zone at a higher elevation.

It is the presumption that the erosion process of the Samala River that has created a deep ravine at the center of this geothermal field has lowered the ground water table on both the banks, and that the lowered ground water table has affected the potential of thermal water reservoir presumed to exist under the ground.

This assumption is supported by the fact that the elevations of the hot-spring immediately below the Zunil Falls in this area and the groups of hot-springs around and at the downstream of the Fumarole Grande are about 80 ~ 100 m lower than that of the higher altered zone at the entrance of the road leading to the Georginas Hot-spring.

However, it is questionable whether this explanation is sufficient, because it is generally inconceivable that the underground water, hot-spring water or thermal water fill the strata extensively as in the case of the underground water in the sand and gravel layers. Particularly in an area where a reservoir must be sought in volcanic rocks like this area, even the rocks with comparatively good permeability such as tuff and tuff breccia cannot be treated in the same way as the ordinary sand gravel layers. Since the fact that the accompanying joint or fissures often serves as a better passage and that the area where these joints or fissures are concentrated may make a good reservoir, must be taken into consideration, the question still remains to be answered.

1-3. State of Thermal Water

It has been mentioned frequently so far that the Zunil Geothermal Area including the Fumarole Grande has a possible geothermal system of the hydrothermal system. Although it is difficult to summarize the favorable conditions of this geothermal area in a few words, attention should be paid in principle to the passage and the reservoir of geothermal fluid and its cap rock.

In the Zunil Geothermal Area, part of Cerro Quemado group of Quaternary volcanic rocks may well serve as the reservoir and cap rocks in some cases, but it can be said that the Zunil group of Tertiary volcanic rocks mainly play the part of reservoir and cap rocks.

For simplification of explanation in this report, it is generally explained with the Zunil group that the poor permeable layers such as compact lava make the cap rocks while such pyroclastic rocks as tuff and tuff breccia, which have good permeability, make the reservoir. In addition, the report also emphasizes the importance of the state of progress of fissures as a factor for determining reservoir rocks and cap rocks. The fracture system naturally has relationship with such geological structure as intrusion of volcanic rocks and faults, and serves as a main passage of the geothermal fluids.

To describe in somewhat textbook fashion, what is related with the reservoir and passage of geothermal fluid are: one is the porosity of rocks and strata, chilled contraction joints of lava and others, bedding plane or particularly the unconformity plain blanketing the weathered surface and other primary structures, and the other belongs to the geological structure of the secondary effect, for instance, joints, fissures and fracture zones accompanying faulting or folding, fracture zones formed around the intrusion of volcanic rocks or volcanic tectonic depressions, concentric and radial faults and fracture system.

Points to be given special attention in the Zunil Geothermal Area are the detailed stratigraphy of the Zunil group, particularly the thickness and the stratigraphy between the lowest formation and the basement granite, the relationship between the Zunil group and granite and the relationship between the geological structure, influenced mainly by the fault system, and intrusive volcanic rocks. These points will be the main subjects for future study.

2. Moyuta Geothermal Area

2-1. Introduction

The following is the outline of findings of the survey conducted in Guinea and Azulco in the Moyuta Geothermal Area, on March 5 and 6, 1973.

Like the Zunil Area which has previously been mentioned and the Ahuachapan

Area in El Salvador which will be described at a later stage, these two areas are closely related to the circum-Pacific volcanic belt which traverses Guatemala and El Salvador and extends in the E-W or WNW-ESE direction and also to the Central graben in Guatemala.

The section of this volcanic belt in Guatemala is said to be approximately 300 km in length and about 70 ~ 130 km in width and its volcanic activity is said to have been in the Late Tertiary the Recent geologic chronologically.

Moyuta and Ahuachapan are only about 35 km apart from each other and both sites have strong similarity in many respects.

2-2. Geology and Geothermal Manifestations

The geology in this area consists mainly of the Quaternary and the Recent volcanic deposits comprising andesitic ~ basaltic lava flows, dark ashes, agglomerates and volcanic breccias.

The Moyuta area has many surface manifestations such as hot-springs, fumaroles and altered zones. Besides, Moyuta Volcano (1,662 m in elevation) accompanied by small volcanoes and many cindercones and lava domes are located close to Moyuta village. These surface manifestations are considered to be distributed along the tectonic line (Fig. VI-3).

2-3. Distribution of Geothermal Manifestations

The survey was conducted in two areas of geothermal manifestations, Azulco and Guinea, both located in the southeastern section of the Moyuta Area and are considered to belong to the same geothermal system. In the neighborhood of these two areas are a total of four fumaroles, namely, (1) Azulco (Las Nomas), (2)Guinea (near Moyuta village), (3) Marcucci and (4) Padre Mariano.

Marcucci is about 1 km north of Guinea and its elevation is about 650 m. Padre Mariano is located outside of the volcanic depression.

2-3-1. Azulco Field

Azulco has an elevation of about 660 m and can be reached on foot in about an hour from Azulco village. As far as the actually surveyed areas are concerned, surface manifestations in Azulco are the largest in scale with a fairly dense distribution of fumaroles, hot-springs and altered zones within a range of about 4 km. Outcrops of development basalt is observed. For alteration, development of

Kaolinization and limonitization is observed. The surface manifestations appear to be distributed along faults or at the crossing of faults.

2-3-2. Guinea Field

Guinea is located very close to the road which has an elevation of about 1,020 m and is accessible by car. Here, fumaroles, hot-springs and mad pots cluster together along a small swamp. At the cutting of the road are outcrops of remarkable white-colored alteration, indicating conspicuous kaolinization. Both in Azulco and Guinea, the temperature of steam or thermal water ranges from 98°C to 100°C.

All of these geothermal manifestations are the results of mixing of steam originating from the underground thermal water reservoir with permeated surface water (shallow ground-water). They do not seem to represent the direct discharge of thermal water from the depth. In this respect, this area bears a strong resemblance to the Ahuachapan Area in El Salvador and is considered to have somewhat different aspects from the Zunil Area. In the Zunil Area it appears that a part of deep thermal water springs out at the bank of the Samala River as geyser or high temperature hot-spring.

2-4. Topography and Other Features

The progress of erosion by river is not so conspicuous in this area as compared with Zunil. That is to say, the elevation of the Azulco area is 600 ~ 1,000 m while that of the Guinea area is 800 ~ 1,000 m and the geothermal manifestations are concentrated in the relatively flat terrain.

In the area adjacent to these two areas in the north, a 500 ~ 600 m wide flatland or a wide valley called the Moyuta-Jalpatagua Valley develops extensively, while in the neighboring areas in the east, west and south, there is a distribution of many lava domes.

Since the area resembles closely to the Ahuachapan area in topography, such operations as geophysical prospecting and test borings will be easy.

The area is very easy of access like the Zunil Area. It is about 110 km from Guatemala City and can be reached by car in about two hours and a half. People are engaged in stock farming and agriculture, and there are coffee plantations. No major obstructions to geothermal development are expected. Purchase of land will encounter no specific problems. It is said that test borings can be made at any place, as there is no law to govern such an operation.

2-5. History of Geothermal Survey

(1) In 1971 a survey was conducted for surface geothermal manifestations throughout the Republic of Guatemala under the aid of the United Nations, and 23 locations were selected, among which the Moyuta Area was considered to be the most promising. In May of the same year, a preliminary geological survey and analysis of thermal water samples were conducted.

(2) A detailed geological survey on a 1/50,000 scale, interpretation of aerial photographs and preparation of tectonic maps in March-May 1972.

(3) Topographical survey (by INDE) and preparation of geological profiles for a distance of 80 km in February 1972.

(4) Present State

1) A gravimetric survey and an electric resistivity survey are under way in the range of about 14 km x 9 km along the planned line shown in Fig. VI-3. Analysis of findings is entrusted to an American firm. Since the I.P. prospecting machine (manufactured by Heinrichs and equipped with a generator), formerly provided by the UN, is used for the electric resistivity survey, the effective depth of prospecting is only about 300 m, which is not enough for desired results.

2) A temperature survey is also being conducted in the same area. Since no boring machines are available from INDE, a Winkie's rig (with a capacity of about 100 m), one of the two drilling rigs owned by Direction General de Mineria e Hydrocarburos (hereinafter referred to as D.G.M.H.), is being used for this purpose.

3) Test borings are being performed for geological survey and for a study of the rate of ground temperature rise. As shown in Fig. VI-3, drilling was already completed at D-H-Jocotillo and D-H-Moyuta and drilling was in progress at DDH-I-Soyatea at the time of this survey. The following is the outline of each test bore.

a) Drilling at D-H-Jocotillo ended at a depth of 400 feet. Soils consist mainly of basalt and clay. Soil temperature was 40°C. A large amount of water flushing at a rate of 700 gal/min was encountered at a depth of 37 feet. Columnar section is shown in Fig. VI-4.

b) Drilling at D-H-Moyuta ended at a depth of 356 feet. Soils consist mainly of acidic tuff and andesitic lava. No spring-water was found. Columnar section is shown in Fig. VI-4.

c) Drilling at DDH-L-Soyatea is still under way for the target depth of 300 m. Soil temperature is 34°C at a depth of 40 feet. A depth of 801 feet was attained at the time of this survey and drilling for a further depth is expected to continue. Operation is being carried out by a crew of seven on a single shift. The crew comprises one operator, one assistant operator, 2 helpers and 3 assistant helpers. As compared with two-men operation in Japan, a crew of seven seems somewhat abnormal even when the cheap labor cost in Guatemala is taken into account. Working hours are from 7:00 to 16:00 hrs with one hour break for lunch. As for the bit size, BX (60 mm) was used at the beginning but AX (49.2 mm) is being used at present. Since no safety equipment such as a preventer are provided, drilling near the spot with geothermal manifestations is being shunned for fear of danger.

The above-mentioned work is being carried out under the supervision of an American Consultants firm. As INDE has no engineer specializing in prospecting, this geothermal prospecting is being conducted jointly by INDE and D.G.M.H. Unlike the work in the Ahuachapan Area in El Salvador, this prospecting is not supported by the UN aids and is financed solely by its own fund.

Since INDE has no prospecting equipment of its own, D.G.M.H. provides necessary equipment for this work. Equipment owned by D.G.M.H. and other related data are as follows.

(1) Geophysical prospecting--One I.P. machine (manufactured by Heinrichs and equipped with a generator), one gravitymeter, two magnetmeters, one resistivity equipment(batteries) and EM-guns (batteries).

(2) Test boring--One Winkie's boring rig of the 100 m class and one Boyles boring rig of the 300 m class, both of which were previously furnished by the UN but their efficiency seems to have decreased considerably. Borings ordered from outside are contracted by Swiss Boring and Dauber and Hoffman Co.

(3) Main engineering staff for prospecting are Mr. Rein Randmets, geologist, Mr. Cesar Recihos, geophysicist and Mr. Radolfo Mendoza, geochemist. It seems that a very few engineers are assigned to the work.

(4) Working conditions--At the boring site in Moyuta, the Wage level was

$250/month for an operator (an additional $50 for work in field) and $100/ month for a helper. The wage paid to a labor hired in Zunil was $1.0 - 1.5/ day. The prevalent wage level is said to be $140/month for a driver, $120/ month for a typist and $140/month for an English-speaking typist.
It is said the workers in field are required to work continuously for 22 days with an 8 day leave. It is said; however, these workers are available for work for more than 22 days in succession if necessary. Twice the normal wage is paid for work on holidays and for work after 6 PM on Saturday.

2-6. Opinions of Mr. Rein Randmets

The following is a summary of a report entitled "Preliminary geologic report of the Moyuta geothermal field, Guatemala", submitted by Mr. Rein Randmets, geologist of D.G.M.H., and was made available to the team. (Refer to Fig. VI-3)

(1) The ground surface is covered with Quaternary andesitic, basaltic lava, pumice and tuff.
(2) Agglomeratic deposits near the ground surface seem to make an ideal cap rock.
(3) As a major structure, the existence of a volcanic-tectonic depression having a shape of the figure 8 is conceived. The larger circle on the north has a diameter of about 18 km and covers an area of about 175 km^2 while the smaller circle on the south has a diameter of 9 km and covers an area of about 95 km^2, with a total area of about 270 km^2. Inside this depression, a block movement took place under the influence of many faults and a number of fissures exist providing an ideal passage for geothermal.
(4) Three fault systems, namely NW system, N-S system and NE system are conceivable. The existence of fault groups is particularly notable in the eastern section of the area. Block movement took place along these faults.
(5) Around the southeastern periphery of this depression are many geothermal manifestations of fumarolic gas and fumarolic water. In particular, Azulco and Guinea show outstanding surface geothermal manifestations suggesting the existence of a good reservoir under the ground.
(6) The fumarolic gas has a maximum temperature of 100°C, and such hydrothermal alteration as kaolinization and limonitization extends over 7 ~ 8 km^2.
(7) Although the content of silica in the thermal water and Na:K ratio indicate some problems, calculation shows an estimated underground temperature of 200°C or more. While the content of Cl in the thermal water is small at 2 ~ 3 ppm, it is considered to represent the heated surface water. Hot-

spring water in the Ahuachapan Area in El Salvador contains 300 ~ 700 ppm of Cl and the thermal water obtained from a deep well is said to contain over 8,000 ppm of Cl.

(8) Judging from the figure of 0 ~ 450 ppm of HCO3 content and the exposure of limestone and marble, in the northern section of the area, the existence of calcareous rocks in the substratum of this area is conceivable. If the area is lucky enough to have such a structure, it should be very similar to Larderello in Italy and there is possibility of dry steam.

2-7. Conclusion

On the basis of the preceding discussions outlining the Moyuta Geothermal Field, it is felt that the area has an equivalent or greater geothermal potential than the Zunil Area. The area is also considered to be more favorable than the Zunil Area in location condition for geothermal development. Zunil, Moyuta and Ahuachapan belong to the same volcanic belt and graben and have similarities among them. In particular, Moyuta and Ahuachapan, only 35 km apart from each other, have strong similarities between them and are considered very promising.

While the joint work of INDE and D.G.M.H. is in progress by their own fund under the supervision of American consultants it is hoped that a further study be made to obtain more accurate data necessary for geothermal development.

3. Ahuachapan Geothermal Field

3-1. Introduction

The team had an opportunity to inspect the Ahuachapan Geothermal Field in El Salvador on March 7, 1973. The following is the outline of the findings and a summary of data obtained at the site. (Refer to the report quoted in Section 3-7)

When the team visited the site, the production well called Ah-12 was being drilled. The total production from the already drilled Ah-1, Ah-5, Ah-6 and Ah-7 wells were approximately 300 T/h of steam and 900 T/h of thermal water. Construction of a 30 MW capacity power plant has already been decided for this area and positive efforts were being made for geothermal development.

The geothermal field under development is located in the western part of El Salvador and is approximately 35 km southeast of the Moyuta Geothermal Field in Guatemala. (Fig. VI-2)

The site is about 3 km east of the Ahuachapan urban area and is easily accessible by car either from Guatemala City, the capital of the Republic of Guatemala or San Salvador, the capital of El Salvador.

The site has a relatively flat topography with an altitude of 700 ~ 1,300 m and its geography bears a strong resemblance to that of Moyuta.

Location condition of the site is very favorable and except some coffee plantations nearby, there seem to be no specific obstructions to geothermal development.

In the town of Ahuachapan there is an office of Estudios de Recursos Geotermicos, where Mr. Jose Esterez, geologist, is in charge. The town is fairly large and has many shops. The site in this environment has a favorable conditions for development.

3-2. History of Geothermal Survey

3-2-1. Initial Survey

The survey of geothermal resources in El Salvador began in 1953 and continued for about six years until 1959 as a joint undertaking of CEL (Commission Ejecutiva Hidro-electrica del Rio Lempa) and Servicio Geologico de El Salvador with the participation of several geothermal specialits, and various geoscientific surveys were conducted and a total of eleven shallow wells were drilled in the Ahuachapan Geothermal Field. On the basis of its conclusion that the site was promising and worthy of a detailed survey, CEL made a request to the Government to apply for financial aid from the UN Special Fund for a feasibility study of geothermal development. The aid from the UN Special Fund was granted in 1965 and a detailed survey was commenced in 1966, which will be outlined hereinafter.

3-2-2. Detailed Survey

A detailed survey was conducted by scientists of El Salvador under the guidance of Mr. Fallen Baily, former project manager, and experts from various countries sent by the UN.

A detailed geological survey and geophysical prospecting were conducted first and the location of exploration wells (deep wells) was selected on the basis of the findings. During the period from March to September 1968, two wells were completed in the Berlin Geothermal Field and three wells (AH-1, Ch-1 and Sa-1) were drilled in the Ahuachapan Geothermal Field. A geochemical prospecting was also conducted in line with the progress of drilling.

Findings of this survey were reported in "Survey of Geothermal Resources, Progress Report, UN-CEL" at the end of 1968.

3-2-3. Second Survey Project

In January 1970 the project manager made public the second survey project centering on deep well borings in the Ahuachapan Geothermal Field under recommendations of the Geothermal Resources Survey Technical Committee for El Salvador (December 1969) of UNDP.

Salient points of the project are as follows.

a) Deep well test borings
   Five exploration wells to a depth of 600 ~ 900 m.
   One reinjection well to a depth of 1,400 m.
   Number of days required: 171 days.
b) Shallow well borings
   Four shallow wells for measurement of water level and analysis of chemical properties of water
c) Hydrogeological survey
   Establishment of a river observation stations and a temperature measurement stations and preparation of hydrogeologic maps by hydrogeologic consultants.
d) Additional geophysical prospecting
   Gravity prospecting in an area extending over 25 km^2 in the east of Chipilapa No. 1 well and establishment of resistivity contour over the entire area of Chipilapa ~ La Labor and Cuyanausul.
e) Age determination of water and measurement of sedimentation in the reinjection well.

Under the program mentioned above, deep wells Ah-5, Ah-6, Ah-7, Ah-9 and Ah-10 were drilled during the period from February to July 1970. About that time, UNDP's Geothermal Resources Survey Team for El Salvador entrusted Mr. John Jonsson, geological consultant of Iceland, with a detailed geological survey in the Ahuachapan Geothermal Field. Included in this survey were:

a) Preparation of a geologic map of 1:25,000 scale covering 100 m^2 of the Ahuachapan Geothermal Field.
b) Comparison between surface geological structure and geology of substratum by test boring.
c) Analysis of geothermal reservoir from combined data obtained from geologic map, geophysical prospecting and geochemical prospecting and test borings.

A total of three months were spent in the field for preparation of the above-mentioned geologic map.

3-2-4. Survey for Development

The following year 1971 was the year of beginning of the survey for development. The UNDP entrusted calculation of total energy potentials of the Ahuachapan Geothermal Field, drafting of a development plan and an economic study of the project to Mr. Gunnar Bodvarsson of the Oregon State University, U.S.A., and Mr. R. S. Bolton of the Ministry of Works, New Zealand on the one hand and asked Mr. R. S. Bolton for necessary measurements of wells. Results of these works were reported in May and June 1971.

The UNDP also entrusted a corrosion test of materials to be used for construction of a geothermal power plant to Mr. W. R. Braithwaite, specialist from New Zealand and an interim report was presented in 1971. The final report on this test is scheduled to be published by the Department of Scientific and Industrial Research in New Zealand upon completion of the test expectedly in early November of this year.

As mentioned so far, the year 1971 was devoted to various studies and researches for development, and drilling of deep wells by CEL without outside help was initiated in 1972 and wells Ah-4, Ah-8, and Ah-11 were completed in the same year. At the time the survey team made a visit to the site, well Ah-12 was being drilled.

3-3. Geology and Geological Structure

3-3-1. Regional Survey (Preliminary)

The existence of a large graben traversing El Salvador in WNW direction has long been suggested by geologists and its extension is believed to reach the neighboring Guatemala. The Ahuachapan Geothermal Field is located near the western periphery of this graben. (Fig. VI-5)

The joint survey oonducted by the UN and CEL in 1968 covered a wide range including Ahuachapan, Playon de Chipilape and Playon de Salitre, in which three exploration wells--Ah-1 (1,205 m), Ch-1 (984.85 m) and Salitre No. 1 (865.5 m)--were drilled along with the surface geological survey. (Fig. VI-6)

Mr. Mario Jimenez compiled the stratigraphy of this field as shown in Table VI-1 from geological data obtained from the surface geological survey and exploratory wells.

With regard to geological structure, the following three fault systems were observed.

a) In WNW direction: A fault that comes in contact with the graben in the south.

b) In NE direction: A predominant fault in the area west of Ahuachapan.

c) In NNW direction: A fault formed following the formation of a fault system in NE direction and the thermal water manifestations in the Laguna Verde area are associated with this system

Fault systems in NE and NNW directions are related with the dislocation of strata of Pliocene series and are believed to have provided a passage for steam in the early stage.

As a result of this survey, the following three locations were selected as areas with signs of geothermal potential.

a) Laguna Verde Area

b) Playon del Salitre Area

c) Rio Paz Area

On the basis of boring data and others, the Laguna Verde Area was determined to be the most important and worthy of a detailed survey. Two exploration wells, Ah-1 and Ch-1, were drilled in the Laguna Verde Area.

Geology of substratum observed at well Ah-1 by Mr. Jimenez is summarized as shown in Fig. VI-7.

Salitre No. 1 well (Sa-1) drilled at Playon del Salitre was a failure.

3-3-2. Detailed Survey

Mr. *Jon Jonsson, geological con*sultant from Iceland, who conducted a geological survey at the request of the UN, prepared a geologic map of 1:25,000 scale of the most important Ahuachapan Area (*An area centering around Ahuachapan City* ~ Laguna Verde) extending over about 100 km^2.

Geology and stratigraphy (*Quaternary*) determined at that time are summarized in Fig. VI-8.

Fig. VI-9 shows an area centering around the Laguna Verde Geothermal Feild, which was extracted from the geologic map prepared by Mr. Jon Jonsson.

Although exploration wells M-1 through M-4 (Maximum depth of 300 m) were drilled in addition to deep wells in this area, the data obtained from these exploration wells were of little help for the establishment of the stratigraphy. However, the petrologic comparison among deep wells Ah-1, Ah-5, Ah-6 and Ah-7 was comparatively easy and more important is the fact that the existence of a zone of higher permeability at about the same depth as those of these deep wells was confirmed (Fig. VI-10).

However, different results were obtained from two deep wells Ah-9 and Ah-10 and this disparity is probably due to the fact that these wells are located outside or on or near the old caldera, which will be described at a later stage.

Fig. VI-11 shows a summary of data on the relationship between the rock facies and the permeable zones in the case of Ah-5 furnished at the site.

Fig. VI-12 shows a summary of comparison data for Ah-1, Ah-9 and Ah-10, particularly a comparison for top horizons of Ancient agglomerates of Pliocene, furnished at the site.

Mr. Jonsson maintains that since the top horizon exists at an altitude of 200 m at well Ah-1 and at the surface outcrop (outcrop in the Paz River) and at an altitude of -100 m or less at well Ah-1, there must be tectonic disturbance between Ah-9 and Ah-1 and stresses that this fact strongly supports the existence of the caldera.

The large geological structure of El Salvador including the Ahuachapan Geothermal Field is the central graben which represents the collapse of geoanticline and strikes approximately E-W.

The fault at the southern limit of this graben is a fault zone dipping in steps on the north side.

Several transvers faults cutting the faults of E-W strike at right angles, which are considered to have an important bearing on geothermal activities, are observed in the western part of Ahuachapan City and each of these transvers faults dips east with blocks between faults tilting to the west. The City of Ahuachapan stands on these tilted blocks.

Formation of these transvers faults in the Ahuachapan Area is considered to be relatively old and to have accompanied the formation of the graben. The subsequent tectonic movement, if any, probably was not so great in intensity.

According to Mr. Mooser (1968), the fault to the east of Ahuachapan City is considered to dip west.

The geothermal fields to the east and north of Ahuachapan City are located in the collapse fault having a nearly triangular shape but whether these faults are important for geothermal activities is the question to be answered in the future.

Though many researchers are inclined to believe that faults are very important factors for the surface geothermal phenomena, small faults in strong volcanic formation may have some influence on the volcanic structure but have no real tectonic significance. Faults of this type are expected to exist at several locations on the north slope of the Laguna Verde Group.

When there is necessity to confirm the existence of faults of this type prior to drilling of a deep well, a detailed geological survey and a geophysical prospecting should be made.

3-4. Geothermal Manifestations (Including results of geophysical prospecting and geochemical prospecting)

It was already mentioned in the previous section that Mr. Mario Jimenez had selected Laguna Verde, Playon de Salitre and Rio Paz as areas with geothermal manifestations from among areas under survey and that he had picked Laguna Verde (or Ahuachapan) Area as the most promising area when a joint survey of the UN and CEL was made.

The Laguna Verde Area is located to the north of a volcano group of the same name. While many fumaroles are observed in this area, there are only a few hot-springs.

As already mentioned in the section (3-3) for geology, the ground surface in this area consists of andesitic and basaltic lava of Quarternary and coarse ~ fine Pyroclastic rocks, with developed fissures. The fock formation is highly permeable and is suitable for the passage of steam and thermal water.

Accordingly, the rock formation has been altered and the existence of clay, pyrite, silica and carbonate is normally observed.

As for physical properties of strata at greater depths (Tertiary system), core samples show low permeability, discontinuity of faults and fissures, as well as less significant hydrothermal alteration. In other words, poor fissures have led to the shell rocks formed by silica or carbonate with little presence of pyrite.

The geophysical prospecting which preceded drilling of deep exploration wells will be described briefly. The geophysical prospecting included the following.

a) Magnetic survey } Over an area of 200 km^2
b) Gravimetric survey }
c) Electric resistivity survey
d) Geothermal gradient survey (24 wells, each having a depth of 100 m and a diameter of $3^1/2$" (NX).
e) Temperature survey (Conducted in the south at a depth of 1.5 m).

Among these surveys, the electric resistivity survey was most influential in the selection of the location of deep exploration wells.

The basic parameters of a geothermal field are temperature and permeability. When the reservoir has a high temperature and a high content of Cl, the electric resistivity survey provides valuable data on temperature at the depths. Although several low electric resistivity zones were observed in the area under survey, high underground temperature cannot be expected from all of these zones.

Hope can be placed only on such zones as the low resistivity zone in Playon de Agua Shuca which is favored with good hydrological and petrological conditions.

On the basis of this assessment, the location of two deep exploration wells, Ahuachapan No. 1 well (Ah-1) and Chipilapa No. 1 well (Ch-1), was selected in May 1967. Analysis of samples from these two wells showed a Cl content of 8,500 p.p.m.

Judging from the data obtained by the resistivity survey and geochemical prospecting and also from the geological structure, the production zone in Ahuachapan Geothermal Field is considered to extend sideways, both to the east and the west of Ah-1 up to the fault striking NNW.

However, Mr. Jimenez recommends a high density resistivity survey in EW direction in the Chipilapa Area.

Besides, Mr. Jose Gonzalez, who conducted the geophysical prospecting, recommends a detailed resistivity survey in the southern section of Los Ausoles to define a $5 \sim 10\Omega$ m zone and in the Labor-Chipilapa Area to determine the eastern boundary of the geothermal field.

Mr. Gudmunder E. Sigvaldason and Mr. Gustavo A. Cueller, who conducted the geochemical prospecting in the Ahuachapan Geothermal Field in the same year reported the following on the findings of their survey of surface geothermal manifestations covering an area of 300 km^2.

a) Fumarolic activities are confined to the north slopes of the volcanic block of $700 \sim 1,400$ m in height. Representative fumaroles are Cuyanansul (Temperature 123°C), El Sauce, Agua Shuca, Playon de Ahuachapan and La Labor.
b) Geothermal steam accompanied by surface alterations is observed in several locations but activities are very weak.
c) Hot-springs are observed on the plains between the southern volcanic block and Rio Paz in the north. Typical hot-springs are Lorenzo, Los Salitres and Los Toles. Hot-spring water in Los Salitres alone flows out from lava of Pliocene Tertiary and hot water in other locations flow out from Quaternary deposits. Temperature of hot-spring water ranges from 40°C to 102°C.

Mr. Sigvaldason and Mr. Cueller, who also conducted a survey of two deep exploration wells, Ah-1 and Ch-1, maintain that a major production zone exists at a depth of 500 m, which is considered to be the boundary between the Tertiary system and the Quarternary system, and another one further below at a depth of 800 m ~ 900 m. Temperatures measured at Ah-1 and Ch-1 are reported to be 228°C and 200°C respectively.

Hydrothermal alteration is not so conspicuous and plagioclase and pyroxene still remain in part. Olivine and vitric groundmass comprise altered chlorite, calcite and secondary quartz. They are also accompanied by epidote or prehnite at a greater depth.

Ah-1 has a wellhead pressure of 9 atg, discharge of 107 kg/sec and steam flow of 35.5 t/h.

Mr. Sigvaldason and Mr. Cueller, after collecting samples from various areas with surface geothermal manifestations and deep exploration wells and summarizing the results of analysis of surface thermal water and hot liquid in the reservoir from Ah-1 in Table-2, state that a theoretical study will be made in the future.

As indicators of temperature, they adopt--Silica (SiO_2) and sodium to potassium Atomic ration (Na/K) in their discussion and also point out chloride and boron, and sulfate and bicarbonate contained in the hot-spring water as interesting subjects of study.

Results of analysis of thermal gas samples obtained from fumaroles were characterized by an extremely low content of H_2S.

The hydrogen content is generally considered to be an indicator of high temperature and a content of 0.5% or more indicates a temperature of 200°C or more in the reservoir. In the area under survey, however, the following values have been registered, which indicate a steady increase toward south.

Playon de Ahuachapan	0.1%
El Sauce	0.3%
Cuyanansul	1.4%
La Labor	0.0%

The amount of non-condensable gas at Ah-1 was relatively small and the gas/water ratio was 15 ml/l in the initial test and 45 ml/l in the subsequent test. Components of gas are shown below, which are characterized by a high content of hydrogen.

CO_2	80	50%
H_2	40	10%
N_2	2	10%

The temperature measured at this well was 228°C, well in conformity with the figure calculated from the silica content in the water. However, the value 270°C is obtained when calculated from Na/K. They say the disparity between these two indicators could be theorized.

With regard to the size of deep reservoir in this area, they maintain that the magnitude cannot be determined with a single method and that it can only be determined from a combination of geochemical data with drilling of deep wells, electric resistivity survey and geothermal gradient survey. They estimate that the deep reservoir in this area extends over 20 - 30 km^2.

For the magnitude of reservoir, Mr. Jonsson considers an area of 38 km^2 with a maximum diameter of 7 km from a geologic and tectonic point of view. (Fig. VI-9)

This range comes close to the old caldera which he has in mind. Since the collapse of a caldera generally create a lake first and the continuation of volcanic activities in the caldera probably causes considerable fracture and brecciation, the rock formation should be highly permeable.

Mr. Jonsson summarizes geological history of the Ahuachapan high temperature geothermal field as follows.

(1) Formation of a large central volcano of the Irazu type. This volcano comprised lava and tuff, with limited geothermal activities.

(2) Formation of a caldera following a major eruption and the subsequent formation of Ancient agglomerates.

(3) Volcanic activities inside the caldera, major geothermal activities and filling of the caldera.

(4) Depression of anticline and formation of the central graben, resumption of volcanic phenomena, activities of Laguna Verde group and complete filling of the caldera with the erupted lava and tuff.

(5) Pause of activities of Laguna Verde group and high temperature geothermal activities.

The above-mentioned geohistory is based on the theory that the existing geothermal area and hydrothermal alteration area reflect the magnitude and configuration of the old caldera.

3-5. Opinions of Mr. Boduarsson and Mr. Bolton

3-5-1. Outline

In 1971 Mr. Gunnar Boduarsson (Oregon State University, U. S. A.) and Mr. R. S. Bolton (Ministry of Works, New Zealand) conducted a joint feasibility study for development. Since they made some interesting recommendations in their report, the outline of these recommendations will be described for information. However, the data (mainly reports of past surveys) furnished to this survey team were only in part and were not sufficient.

Their survey was conducted during the period of May through June 1971 at the request of UNDP's Geothermal Resources Prospecting Team for El Salvador and their report covers mainly physical characteristics and economical potential of the geothermal field.

3-5-2. Main Subjects of Study

(1) The known vertical tectonic (maximum depth of test boring being 1,200 m) is characterized by three ground water tables and the stratum that has direct bearing on production is the third ground water table. This horizon comprises gray lavas extending from an elevation of 300 m to the lower strata (to unknown depth). All production wells get supply from this horizon. The temperature in the well is almost constant between this stratum to a depth of 1,200 m with very minor changes of 10° ~ 20°C/km (1 ~ 2°C/100 m).

While the porosity and permeability of the stratum are very small, several large horizontal sheet-like strata with high permeability or tube-like opening with a large flow form a large horizontal section with good permeability.

(2) The thermal water produced is not chemically homogeneous. Variation in Cl content reaches 25% between individual wells. This indicates the presence of several different ingredients in the water in local reservoirs. Temperature calculated from SiO_2 and Na/K is 245°C-255°C as compared with the maximum-measured temperature of 236°C. This is interpreted as an indication of minor evaporation of geothermal steam due to the escape of temperature and thermal gas (Sigvaldason and Cuellar 1970 Glover 1970). The evaporated geothermal steam may become a thermal source for the ground water system near the surface.

A study of dueterium in the surface water and the reservoir water shows that the reservoir water is originally rainwater. Therefore, saline water is not sea water in origin and the salinity in water is only a result of condensation by evaporation.

(3) The geothermal system in this area is said to be under the influence of the structure of a collapsed caldera. Mr. Jonsson estimates the diameter of the caldera to be 7 km. His estimate is based mainly on the distribution of surface geothermal activities and altered rocks. He also points out that the structural disconformity shown by boring at Ah-9 supports the caldera hypothesis. (Fig. VI-13) However, his opinions on this point are not consistent.

(4) Microearthquake surveys conducted by Mr. Ward and Mr. Jacob (1971) indicates the existence of an active fault type tectonic with a strike of about N10°E and a dip of about 80°E. These faults of N-S system exist almost in

parallel and at intervals of about 2 km. (Fig. VI-13) This theory of faults is also supported by the fault breccia found by the test boring of Ah-9.

According to the microearthquake survey of the Ahuachapan Area, its hypocenters are of a structural origin and are concentrated at a certain location. The hypocenters in this area seem to be different from those in Iceland where they are irregularly distributed below the surface activities. In the Ahuachapan Area, they seem to have more direct bearing on the source of geothermal activities.

What is meant by him is that different from Iceland, the source of geothermal activities in this area is not located immediately below the main areas with surface manifestations but is located a little far from them either to the south or to the east.

(5) The hydrostatic pressures in wells Ah-1, Ah-5, Ah-6 Ah-7, Ah-9 and Ch-1 indicate a uniform distribution of pressure across the entire field.

The hydrostatic pressure at sea level is about 22.5 kg/cm^2 and the ground water table is about 600 m above sea level. There have been no appreciable changes in pressure since the start of the development. While the pressure at production well Ah-1 shows only minor changes, the pressure at Ah-5 shows a decrease of 14 kg/cm^2 at the time of maximum flow.

This indicates the relatively low permeability of stratum below the horizon of the third ground water table. However, the absolute permeability of this stratum may be considered to be quite high, as the pressure recovers quickly after the well is closed.

(6) The most outstanding feature in the temperature measurement is that the temperature distributions at different depths in wells Ah-1, Ah-5, Ah-6 and Ah-7 are very similar to one another. (Fig. VI-14)

The temperature is highest at a point 250 m above sea level and a decrease of temperature or temperature and down to 50 m above sea level. The temperature is constant in wells deeper than this level. As in case of pressure, there have been no appreciable changes in temperature since the start of the development.

(7) It may well be said that there is no need to drill production wells below sea level or to a depth of more than 800 m. The following hypotheses may be used to explain the temperature inversion.

a) Mixture with colder water from a deeper source.

b) Casual flow of thermal water from a remote source (This system is at thermal non-equilibrium).

c) Increased flow by boring create a thermal non-equilibrium and causes flow from a remote source.

d) Secondary vertical convection in the ascending hydrothermal system.

e) The measured temperature does not represent a true value but shows a local thermal phenomenon in the well or represents an error in measurement.

(8) Source Models

The following two types of source models may be considered.

a) A local thermal source below the geothermal field, namely caldera model.

b) A remote source model of the main thermal source in the southeast by south of the Ahuachapan Geothermal Field.

(9) For the development of geothermal resources, it is advisable to base the planning on the most conservative estimate of energy reserves. It is also desirable to increase power generating capacity gradually and construct power plants in stages and at intervals.

Since the term of amortization of the investment for a power plant is normally 15-25 years, the construction of a power plant in the Ahuachapan Area must take into account a service life of the facilities not exceeding 25 years.

However, this service life seems to be rather short from a national point of view and therefore, a alonger service life than 25 years may be considered if there is a possibility of further expansion of the reservoir. In this report a basic project period of 50 years was considered. This means that the development will continue for 50 years for a total power production of 100 MW.

It is desirable to construct three 33 MW power plants in three stages during a period of 12-15 years and expand the capacity gradually thereafter.

1974	33 MW
1979	33 MW
1984	33 MW

(An operating period of 50 years is considered)

If the concept of remote source models is applied, the actual capacity will expand further. This point will be clarified in the next few years by additional prospectings.

(10) Wells

a) Production rate is 50 ~ 120 kg/sec (180 t/h ~ 432 t/h, thermal water: steam ratio = 3:1).

b) Well head pressure with a $9^{5}/8''$ diameter pipe is 6 Ata.

c) Production strata are at depths of 500 m ~ 1,200 m.

One production well is considered to have a capacity of 5 MW and a total of 20 wells will be required for generation of 100 MW. With the addition of five more wells for standby, a total of 25 wells will be required eventually. By allowing a 10% reserve capacity for the first 33 MW power plant unit, additional 3 new wells will be required in addition to the existing 4 wells.

At present, steam is being produced at wells Ah-1, 5, 6 and 7 in the area extending over 1 - 2 km^2.

As previously mentioned, the concept of source models suggests the possibility of steam production in the area of a wider range in the east or in the southeast.

Areas under consideration for future production wells are shown in Fig. VI-15. A higher temperature can be expected from the remote source model which is considered to exist in the area of a little higher elevation in the east or in the southeast.

(11) Because of possible contamination of Rio Paz, disposal of thermal water on the ground will present many problems. Therefore, reinjection of waste thermal water must be considered. Reinjection of thermal water at temperatures 150°C ~ 160°C into the third ground water table will not be too difficult. Reinjection of thermal water at Ah-5 for a period of about three months showed no adverse effects such as the sedimentation of minerals, etc.

If reinjection is made maintaining a minimum distance from the well and to a sufficient depth, adverse effects over a long period of time may be avaidable.

It is advisable to select the location of a reinjection well for the first 33 MW power plant at a distance of more than 2.5 km from the main steam production area in consideration of the consequence over a long period of time. The proposed location of such a reinjection well is shown in Fig. VI-15.

For the operation of a 33 MW power plant, two wells with a capacity of 250 kg/sec (900 t/h) will be required. It is advisable to drill 3 wells having a maximum depth of 1,200 m in consideration of failure of one of the wells.

It has not yet been determined whether the thermal water can be re-injected at a temperature of less than 150°C without causing sedimentation of SiO_2 in the pipe. However, reinjection at lower temperatures is considered possible and it is recommended to conduct a field test in the future, particularly at a low temperature of 100°C.

(12) Though the survey of this area was conducted in various aspects, very little is known about the structure of thermal system. As previously stated, no conclusion has yet been reached about the thermal system and source models. Although the concept of remote source models is an appropriate hypothesis, it lacks a definite field evidence. This is a question to be answered in the future.

The microearthquake method will be the only available geophysical prospecting method to clarify this question. Also, a vertical seismic profile of the Ahuachapan Area will be very helpful. This profile can be obtained from a prospecting using the microearthquake method or a prospecting centering on seismic refraction survey. More accurate data will be obtained by the latter method.

It is important that adequate instrumentation is provided to obtain accurate data on flows, pressures and chemistry with the wells. Levels and formation pressures must be closely observed at appropriate intervals. A microgravity survey should also be conducted to determine the gross withdrawal of fluids from this area.

It is said that the accuracy of measurements at the bottom of wells, planning of routine test programs, and recording should be carried out as part of field management (Bolton, 1971)

3-5-3. Outline of Conclusions and Recommendations

(1) The primary source of the Ahuachapan Geothermal Field is located a little far from this field to the south and southeast. The thermal system is not under the influence of the structure of the collapse caldera.

(2) Local reservoirs in the Ahuachapan Area are considered to extend over 40 km^3 and the average temperature is estimated at 228°C. The minimum net energy available from a single flash operation is nominally 5 GWY or 4×10^{10} KWH. There is a possibility that the reservoir actually available is in the unit greater than magnitude.

(3) Reservoir with the most conservatively estimated capacity will be used as the basis of development planning of geothermal resources in the Ahuachapan Area. The following development plan is generally considered.

1974	33 MW
1979	33 MW
1984	33 MW

(A service life of 50 years is considered)

(4) Three additional production wells are to be drilled for the first 33 MW power plant and the location of one well has already been selected. The area around Ah-1 is considered suitable for drilling the remaining two wells. For generation of a new 100 MW, 25 additional wells will have to be drilled. The outline of the area under consideration for future prospecting as a site of production wells is shown in Fig. VI-15. However, drilling of wells in group is strongly recommended.

(5) Production cost of steam, including the cost of branch lines and wellhead equipment, for the first 33 MW power plant is estimated at 1.09 ~ 1.31 mills/kwhr, but it will vary with the rate of depreciation and the interest rate.

(6) On the basis of the results of the recent field test, reinjection of thermal water into local reservoir at 150°C without adverse effect is considered possible.

Drilling of 3 wells to a depth of more than 1,200 m in the initial stage of power generation is recommended. Locations of these wells are shown in Fig. VI-15.

The cost of reinjection varies with the service life, rate of depreciation and interest rate for the specific well but is roughly estimated at 1.15 ~ 1.87 mills/kwhr.

(7) It is considered possible to lower the temperature below 150°C for reinjection. It is advisable to conduct reinjection tests at lowered temperatures.

(8) It is recommended to include the microearthquake survey and the microgravity survey in the future geophysical prospecting.

(9) a) Use of a $13^3/8''$ O.D. pipe for drilling will increase production by more than 40% as compared with a $9^5/8''$ O.D. pipe. In this case, however, a larger capacity of winches and pumps will be required.

b) A minor decrease in pressure around well Ah-1 indicates good permeability and this type of well suggests the advisability of spacing wells closer. In other words, drilling of wells in group (at intervals if not more than 50 m) will be more economical.

c) Use of $13^3/8'''$ pipes will reduce the number of production wells to 10, all of which may be drilled around well Ah-1. However, there are still many points to be clarified, and drilling of wells in group and reinjection must be planned carefully.

d) Drilling to a depth of more than 800 m is not required.

(10) The temperature inversion observed in wells in the Ahuachapan Area seems to be useful for analysis of conditions of source. In well Ah-1, the static temperature decreases 5°C between an altitude of +200 m and an altitude of -100 m and the average temperature inversion is 16°C/km (1.6°C/100 m). The gradient of the maximum temperature drop is somewhat steeper or about 25°C/km (2.5°C/100 m).

This may be explained by the horizontal flow of thermal water from a remote source which has recently come to be mentioned frequently. However, the available data are not sufficient to go into detail of this subject.

3-6. Present State of Ahuachapan Geothermal Field

The preceding discussions dealt with the background, geology and tectonic, geothermal manifestations, items of study and features of the Ahuachapan Geothermal Field. At present, each of Ah-1, 5, 6, and 7 is producing 50 ~ 170 kg/sec (180 t/h - 432 t/h) of steam and thermal water. The two-phase flow produces steam at a rate of about 300 t/h and thermal water at a rate of about 900 t/h and the steam/thermal water ratio is 1/3.

The team was informed that the two-phase flow at Ah-4 is presently produced at a rate of 500 t/h (138 t/h of steam and 362 t/h of thermal water), though the data furnished to the team lack this information. Therefore, the gross production at present is 430 t/h of steam and 1,260 t/h of thermal water.

Conditions of each well (as of September 19, 1962) are shown in Table VI-3.

Ah-12 well was being drilled at the time the team visited the site. Drilling was being made by Foramines Drilling Co. of El Salvador using a 5,000 m class boring rig. Details of operation are not available, but the unit cost per meter excluding the cost of cement, pipes and oils was said to be $150. The operation was being carried out in three shifts (8h x 3) and a crew of 8 to 10 workers was assigned to each shift.

Key members of the El Salvador group concerned with this project are Mr. Jose Estevez (geologist, resident engineer), Mr. Alberto Vides (civil engineer), Mr. Mario Jimenez (geologist), Mr. Mauricio Menendes (electrical engineer) and Mr. Gustavo Cuellar (geochemist).

Present arrangement of wells and the proposed site of the geothermal power plant are shown in Fig. VI-16.

3-7. Reference Reports

The reports on the Ahuachapan Area furnished to the team are listed below.

(1) UN - CEL — Survey of Geothermal Resources El Salvador, Progress Report, December 1968

Title	Author
Introduction	
Reporte Geologico del Area de Ahuachapan	Eng. Mario Jimenez
Levantamientos Geologicos en la Area Geotermal de Ahuachapan	Eng. Jose Gonzalez Garcia
Geochemistry of the Ahuachapan Thermal Area	Dr. Gudmundur E. Sigvaldason and Mr. Gustavo Cueller
Informe de Perforacion Y Mediciones de Temperature	Eng. Alberto Vides R.
Testing of Well No. 1 Ahuachapan	Dr. Sveinbjorn Bjornsson
Proposal for Further Drilling in the Ahuachapan Field	Dr. Sveinbjorn Bjornsson, Eng. Jose Gonzales G. and Mario Jimenez
Suggestions for Drilling Programme in the Ahuachapan Area	Eng. Petur K. Sverrisson

(2) Project Manager UNDP — Survey of Geothermal Resources El Salvador. Work Plan for Stage 2 of Phase II including Programme, January 1970

(3) William J. Turner, — Results of Field Test for Feasibility of Subsurface Disposal of Saline Water in Chipilapa-1 Well, March 1970 (UNDP Survey of Geothermal Resources, El Salvador)

(4) John Jónsson, Report on Geological Investigations in Ahuachapan, July 1970 (UNDP Survey of Geothermal Resources, El Salvador)

(5) W. R. Braithwaite, Program for Testing the Corrosion Resistance of Engineering Materials for a Geothermal Power Plant at the Ahuachapan Geothermal Field, September 1970 (UNDP Survey of Geothermal Resources, El Salvador)

(6) Gunnar Bodvarsson and R. S. Bolton, A Study of the Ahuachapan Geothermal Field, May 1971 (UNDP Survey of Geothermal Resources, El Salvador)

(7) R. S. Bolton, A Commentary on Well Measurement and Measurement Programmes, June 1971 (UNDP Survey of Geothermal Resources, El Salvador)

(8) W. R. Braithwaite, Interim Report on the Corrosion Test Program on Engineering Materials for the Ahuachapan Geothermal Power Plant, September 1971

3-8. Conclusions

The outline of the Ahuachapan Geothermal Field in El Salvador has been described so far, but the survey made by this team is not considered complete because of the limited time and the availability of only part of the necessary data.

The first survey of the Ahuachapan Area was conducted in 1953 jointly by CEL and Servicio Geologico de El Salvador. It is twenty years now since the first survey. In the meantime, the UN aids to the project and a survey by the UN began in 1966. Approximately seven years have passed since the beginning of the work by the UN.

The project finally succeeded in the production of geothermal steam and preparations are under way for construction of a geothermal power plant which has been formally decided.

During this period, preliminary surveys and detailed surveys have been conducted by various methods including the geological survey, geophysical prospecting, geochemical prospecting, test borings, corrosion test and reinjection test.

The Ahuachapan Geothermal Field has many aspects similar to the Zunil Area in Guatemala and the data obtained will be very useful for the future study of the Zunil Area. Zunil and Moyuta have many similarities in geology as previously mentioned and the development of geothermal resources in Guatemala is very promising.

For those reports in Spanish among the reports cited, valuable help was extended by Mr. Takeo Seki of Dia Consultants Co., to whom the team expresses its deep gratitude and appreciation.

Table VI - I STRATIGRAPHY

Geol - Age		Thick of Formation	Rock Facies
Quarternary	Pleistocene	400^{m} ~ 600^{m}	Thick pumice tuffs. Basic lavas. Pyroclastics. Grey welded tuff. Severe weakered tuff and pumice. Dark grey agglomeratic tuff. Thick lamiated basic lava.
Tertiary	Pliocene		Red horizon : yellowish red tuff and agglomerate Basic lavas and agglomerate with middle to high density. Compact tuffs.

REMARK : AFTER MR. MARIO JIMENEZ'S DATA (JUNE .1973)

Table VI-2 ANALISIS OF THERMAL WATER FROM FUMAROLE AND Ah-1 DEEP WELL

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	183	167	148	133	91	85	120	102	101.5	97	(456)
Na	417	403	210	124	460	450	495	520	521	520	5025
K	57	53	42	28	11.3	11.3	15.7	20.1	19.5	19.3	905
Ca	48	48	29	26	189.5	187.5	136.2	112.4	96.8	105.3	354
Mg	13.2	13.2	14	17	10.9	12	13.8	8.9	13.8	10.2	23.4
Cl	596	581	323	193	406	405	612	711	681	709	8730
F	0.2	0.2			2.0	2.0	2.0				1.5
SO_4	49.5	58.0	19	11	860	830	540	575	535	555	28
HCO_3	348	342	251	224	24.4	12.0	61	4.9	4.9	4.9	49
CO_3								15.6	15.6	15.6	
B	(10)	(10)	6.7	4.1	6.4	6.3	11.8	15.5	13.6	13.8	131
PH	8.32	8.12	7.33	7.42	8.43	8.43	8.19	8.29	8.26	8.22	7.02
MHO					2.71-10-3	2.68-10-3	2.79-10-3				2.3x10-2
T°C		63	43	36	90	90	50	101	102	101	(220)

1. El Playon de Salitre, March 1968
2. Playon de Salitre, March 1968
3. San Lorenzo, July 1968
4. San Lorenzo, July 1968
5. Los Salitres, May 1968
6. Los Salitres, May 1968
7. Rio Paz, border marker at Paso Jobo, May 1968
8. Los Toles, July 1968
9. Los Toles, July 1968
10. Los Toles, July 1968
11. Ahuachapan No.1-drill hole (7.6 · 68)

(According to enthalpy measurements the analysis of the Ahuachapan reservoir fluid in this table should be corrected using a factor of 0·963)

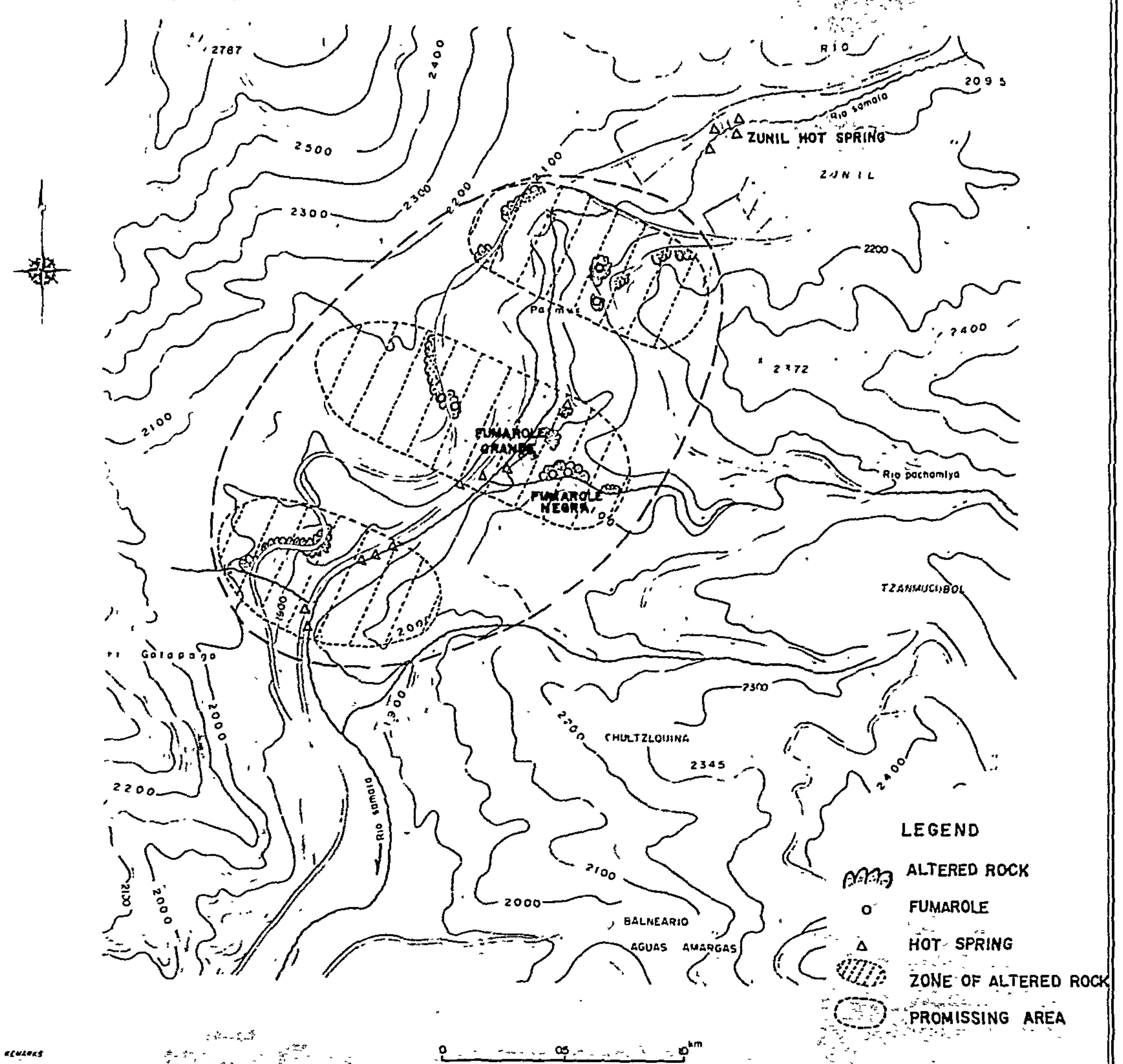
Table VI – 3 DRILLED HOLES AND PROJECTED HOLES IN THE AHUACHAPAN AREA

(Report on 19th Sept. 1972)

Hole No.	Contractor and Period	Dates of Initiation and Termination	Elevation above Sea Level (meters)	Production Pipe		Slotted Pipe		Total Depth		Production		Pressure in Hole Head	Diameter of Discharge Pipe	Chemical Composition					
				Diameter (inches)	Depth (meters)	Diameter (inches)	Depth (meters)	Diameter (inches)	Depth (meters)	Total (T/H)	Vapor (T/H)	(kg/cm²)	(inches)	Total Solids (P.P.m)	Chlorides (P.P.m)	Boron (P.P.m)	Sulphates (P.P.m)	Mixed CO2 (millimoles)	Mixed SH2 (100 moles)
Ah – 1	Loftland Bros 1st Phase ONU – CEL	Apl. 25, 1968 Jun. 1, 1968	802.79	9 5/8 O.D	486.16	—	—	8 3/4 ø	1205.00	325.04	87.30	10.08	10.05 ø	19 300	10 890	162	34	2.43	0.137
Ah – 5	Loftland Bros. 2nd Phase ONU – CEL	Jun. 6, 1970 Jul. 1, 1970	789.45	9 5/8 O.D	456.93			8 3/4 ø	951.63	234.72	58.14	7.22	6.37 ø	16 700	9370	134	35	2.82	0.083
Ah – 6	Loftland Bros. 2nd Phase ONU – CEL	Feb. 2, 1970 Feb. 25, 1970	782.97	9 5/8 O.D	454.30	—	—	8 3/4 ø	591.16	346.03	97.52	7.10	10.05 ø	20 500	11 665	178.5	34	1.15	0.120
Ah – 7	Loftland Bros. 2nd Phase ONU – CEL	May 22, 1970 Jun. 4, 1970	804.79	9 5/8 O.D	483.36			8 3/4 ø	950	301.68	48.49	6.02	6.37 ø	21 600	12 298	188.3	35	2.11	0.153
Ah – 9	Loftland Bros. 2nd Phase ONU – CEL	Feb. 28, 1970 Mar. 27, 1970	871.33	9 5/8 O.D	484.48	7 5/8 OD 7 O.D 5 O.D	1 424.03	8 3/4 ø	1424.03	Production intermittent bad Permeability				40 137	24 300	300	50	Data no Confident	
Ah – 10	Loftland Bros. 2nd Phase ONU – CEL	Mar. 31, 1970 May. 18, 1970	723.78	9 5/8 O.D	485.59	7 5/8 O.	1524.00	8 3/4 ø	1524.00	Reinjection hole : Impermeable				Normal : outside of Geothermal region				—	—
Ah – 4	Foramines S.A. CEL Project	Jun. 1, 1972 Aug. 4, 1972	812.23	13 3/8 O.D	487.16	—	—	12 1/2 ø	640.00	500		8.40	Head 9.5 ø	15 606	8 705	117.2	33	Instable Expansion of hole not yet	
Ah 8	Foramines S.A. CEL Project	Aug. 8, 1972 Sep. 18, 1972	810.99	13 3/8 O.D	469.23	—	—	12 1/2 ø	988.00	Measurement not yet, as of Sep. 19, 1972				No data as of Sep. 19, 1972					
Ah – 2	Foramines S.A. CEL Project																		
Ah – 3	Foramines S.A. CEL Project																		
Ah – 11	Foramines S.A CEL Project																		
Ah – 12	Foramines S.A. CEL Project																		
Ah – 13																			
Ah – 14																			

REMARK : COMPILED BY K. WATANABE FROM CEL'S RECORD

Fig. VI-1 DISTRIBUTION MAP OF GEOTHERMAL MANIFESTATIONS IN THE ZUNIL FIELD, GUATEMALA



REMARKS
ORIGINATED FROM THE TOPOGRAPHICAL MAP "QUEZALTENANGO" (1:50,000)
AND REVISED BY H. WATANABE AND NAKAMURA'S FIELD SURVEY, MARCH 1973.

Fig. VI - 2

LOCATION MAP of ZUNIL MOYUTA & AHUACHAPAN GEOTHERMAL AREAS

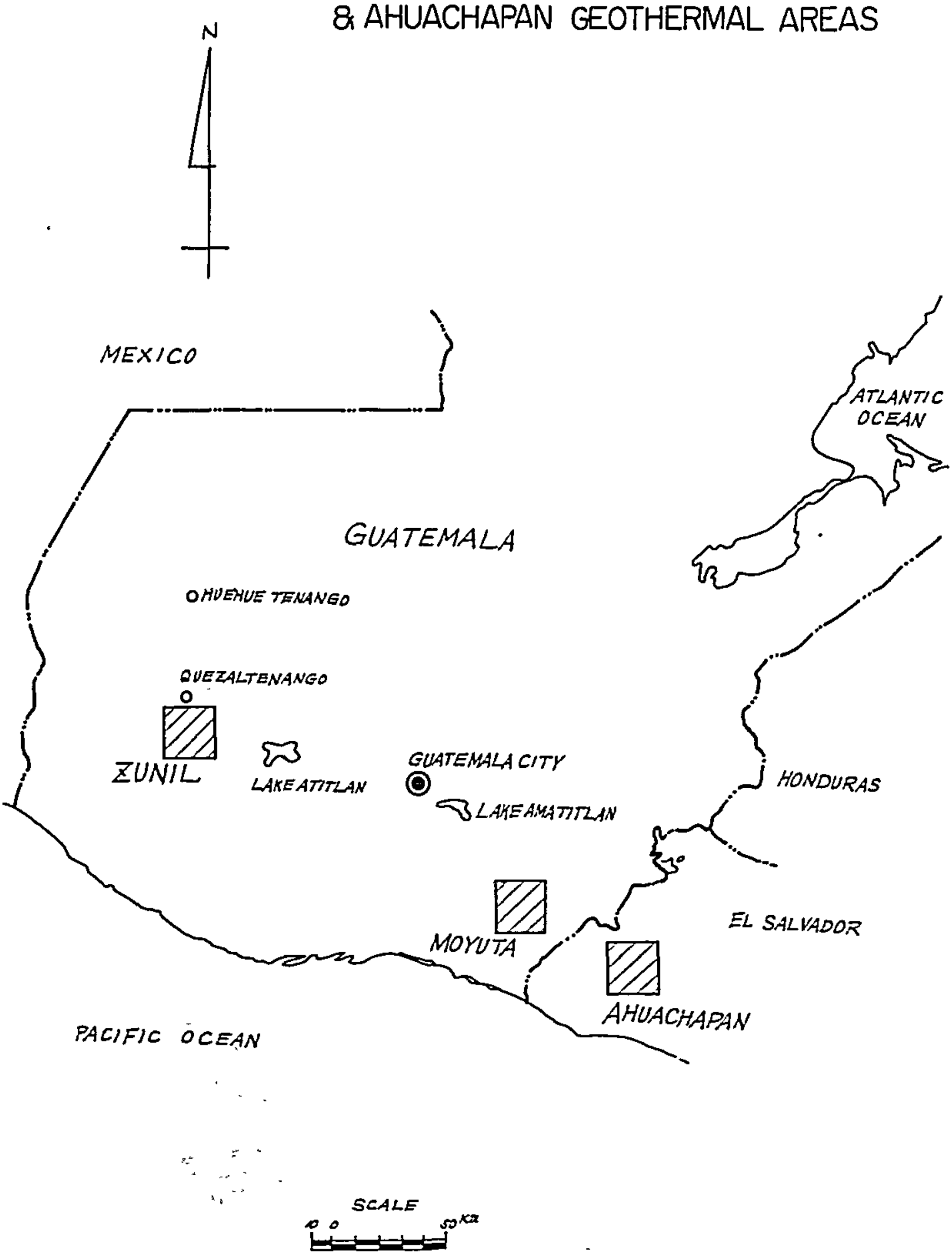
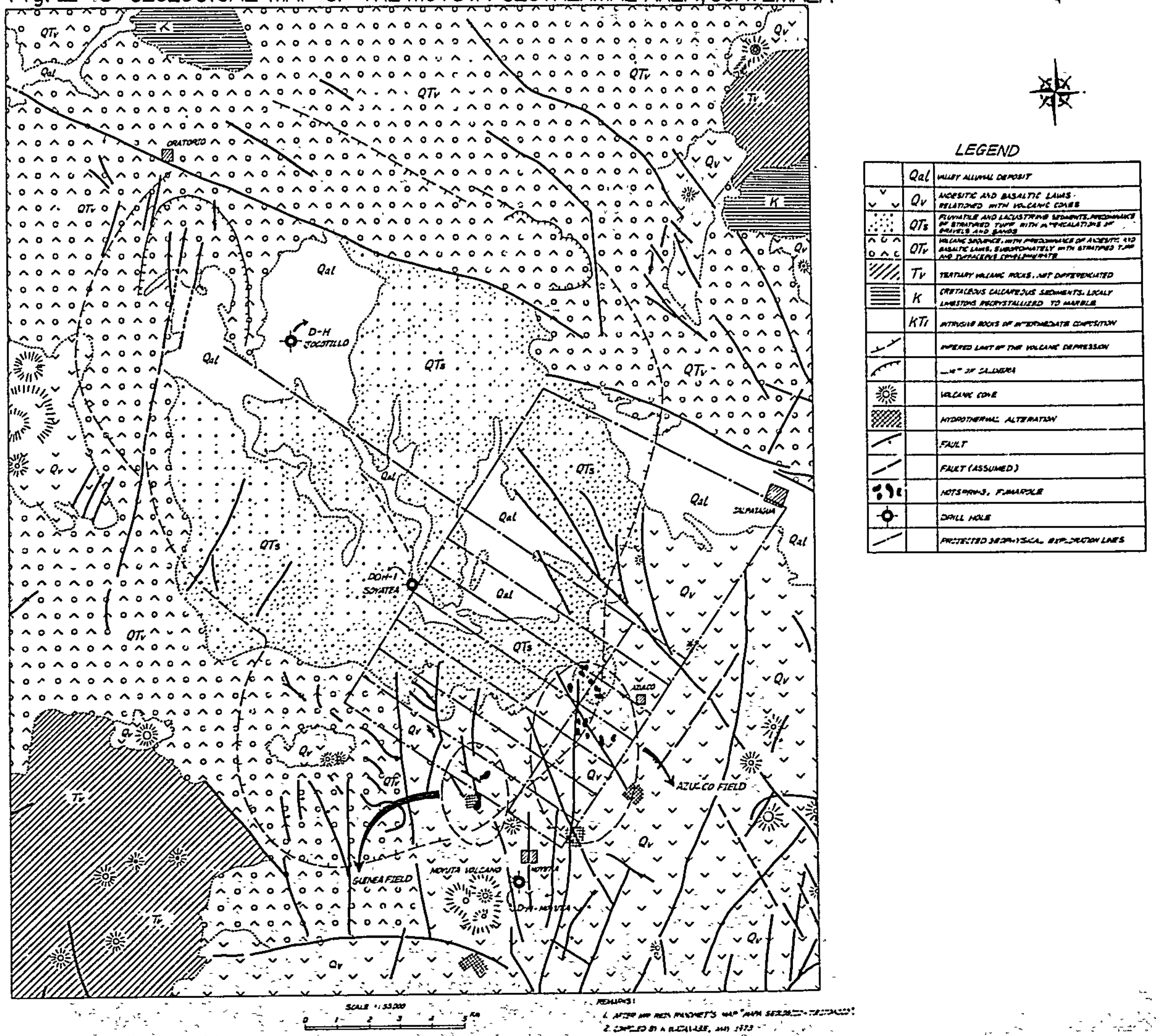


Fig. VI-3 GEOLOGICAL MAP OF THE MOYUTA GEOTHERMAL AREA, GUATEMALA



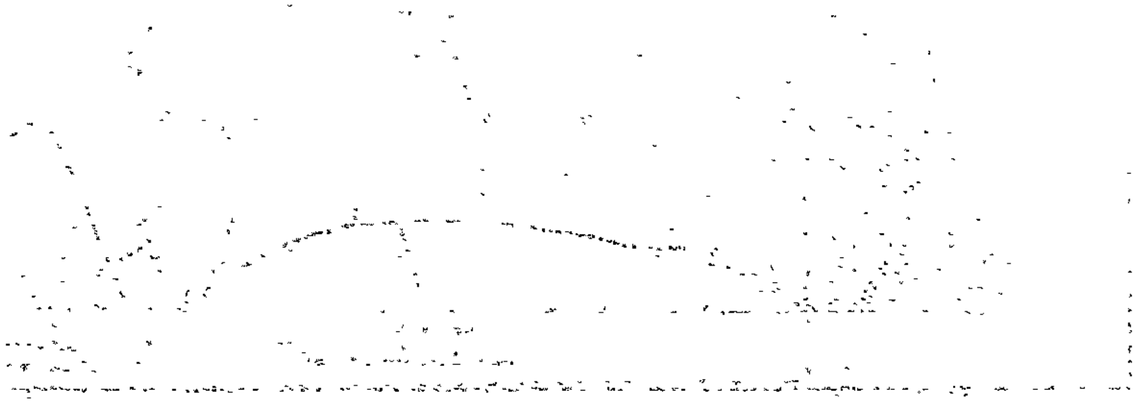
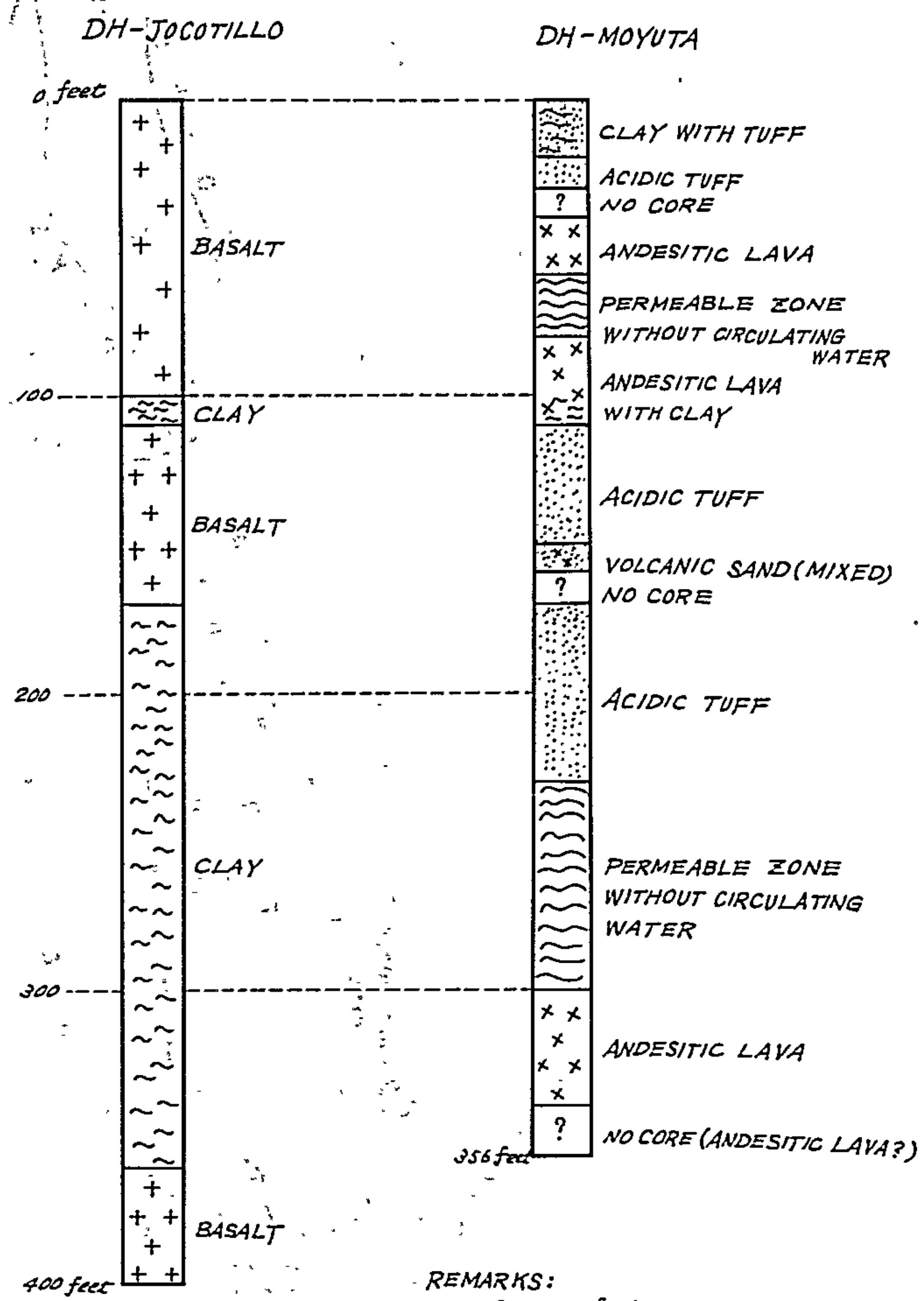


Fig. VI-4

GEOLOGICAL COLUMN of HOLES IN MOYUTA THERMAL FIELD



REMARKS:
(1) 1 cm = 20 feet
(2) ORIGINATED FROM MR. R. RANDMETS'S RECORD

Fig. VI-5 LOCALIZATION OF THE AHUACHAPAN GEOTHERMAL AREA EL SALVADOR

(After Mario Jimenez's Map)

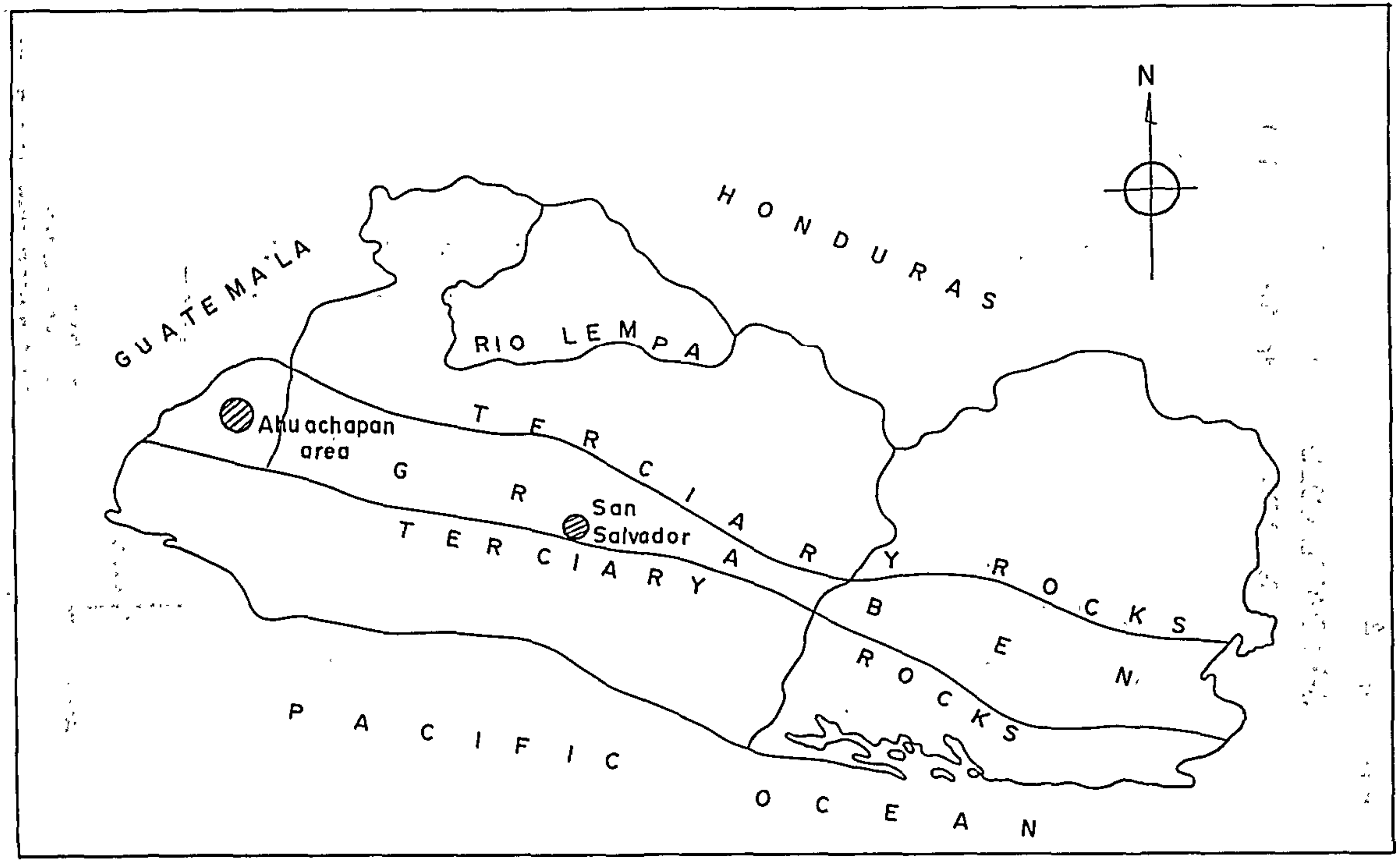
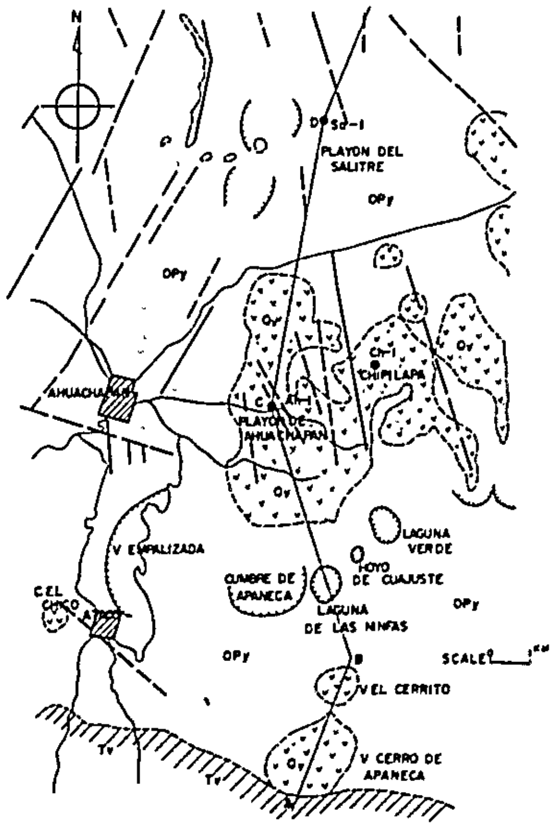


Fig. VI – 6 GEOLOGICAL MAP OF THE AHUACHAPAN GEOTHERMAL AREA

(After Mano Jimenza Map)



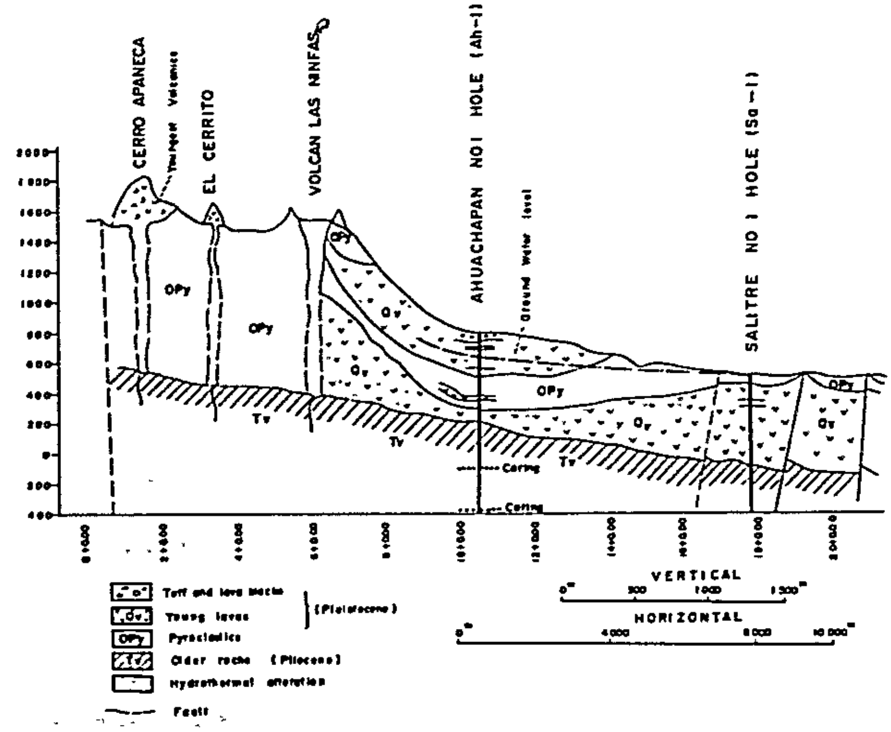


Fig. Ⅵ − 7 AHUACHAPAN COLUMN

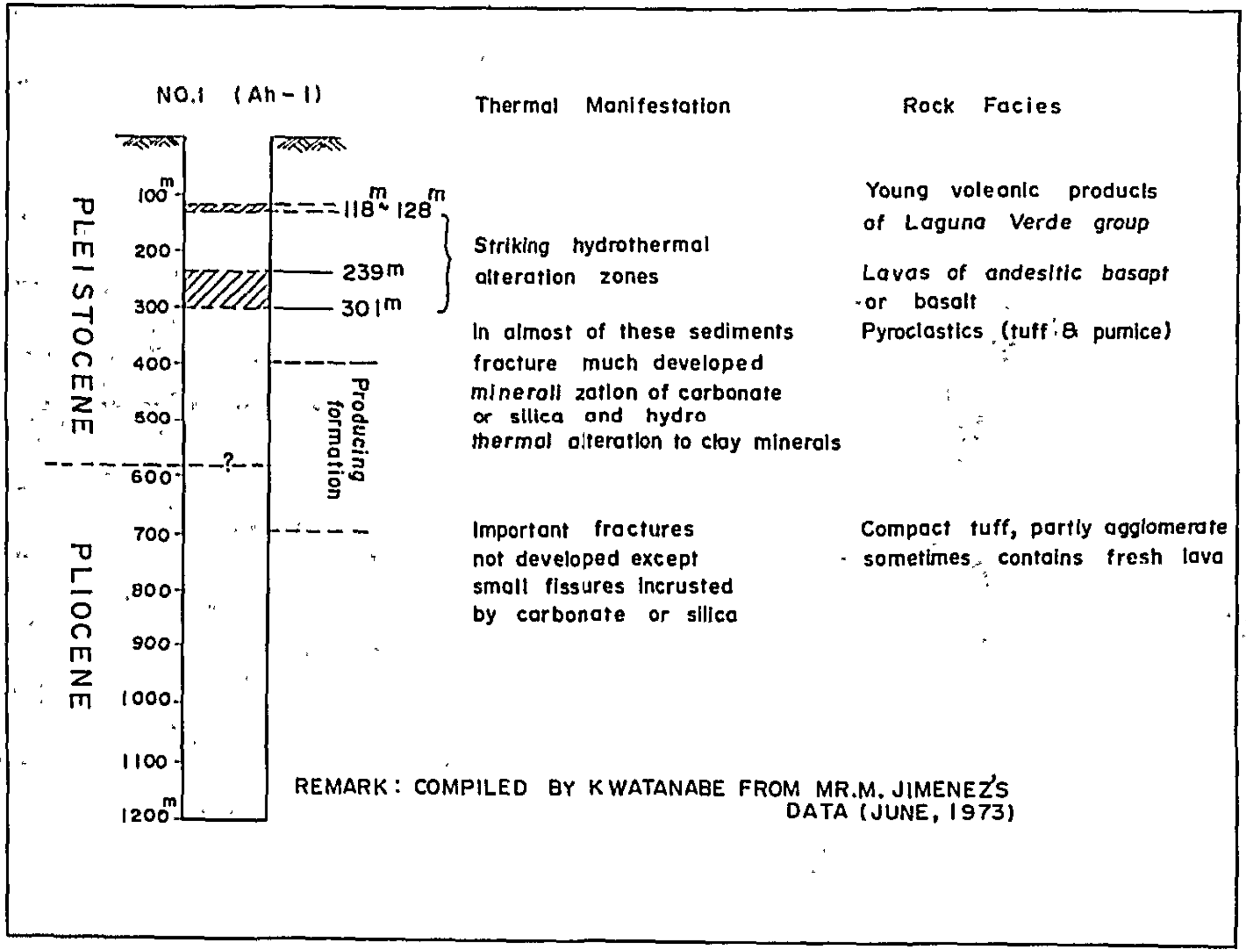
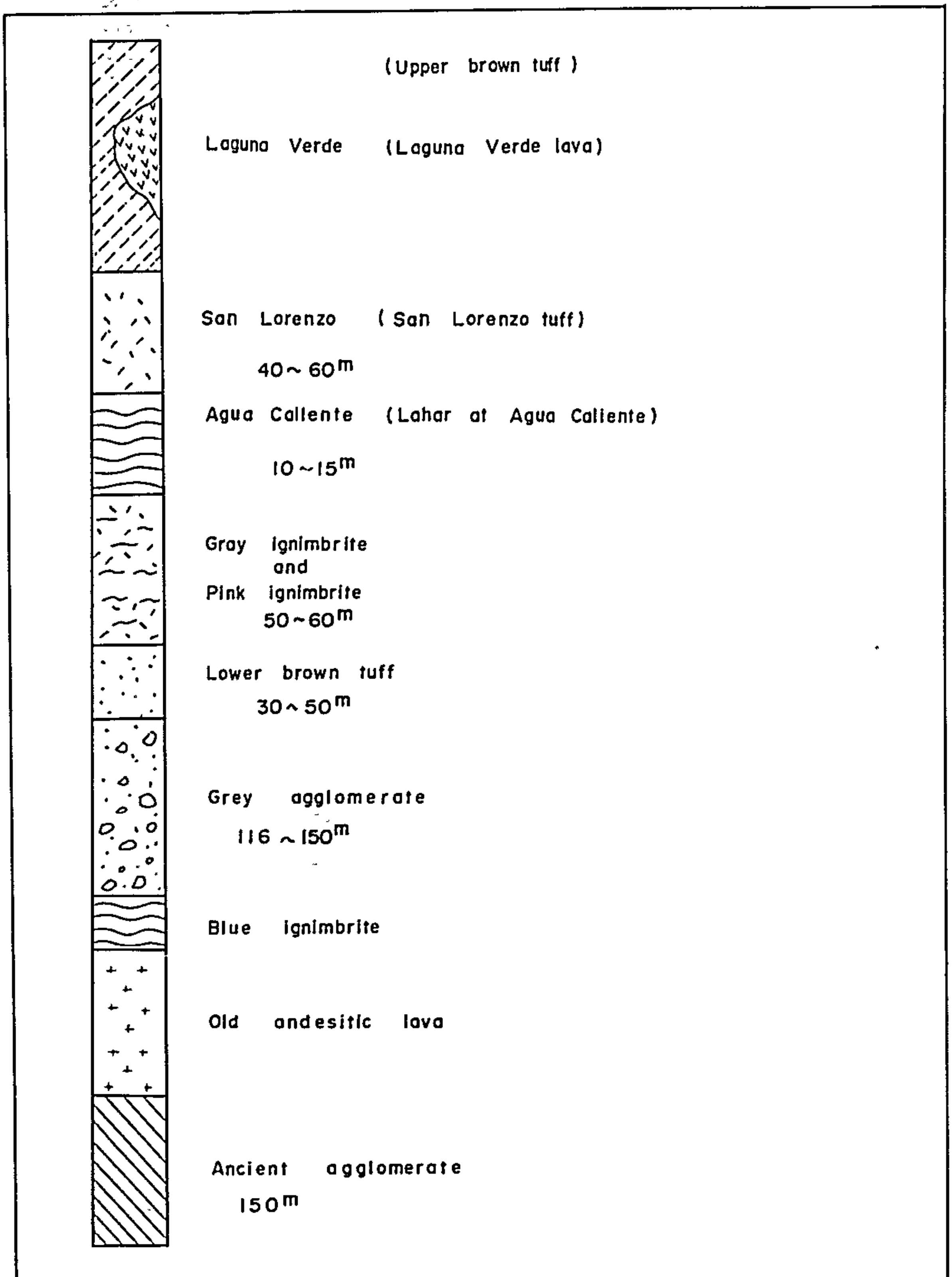
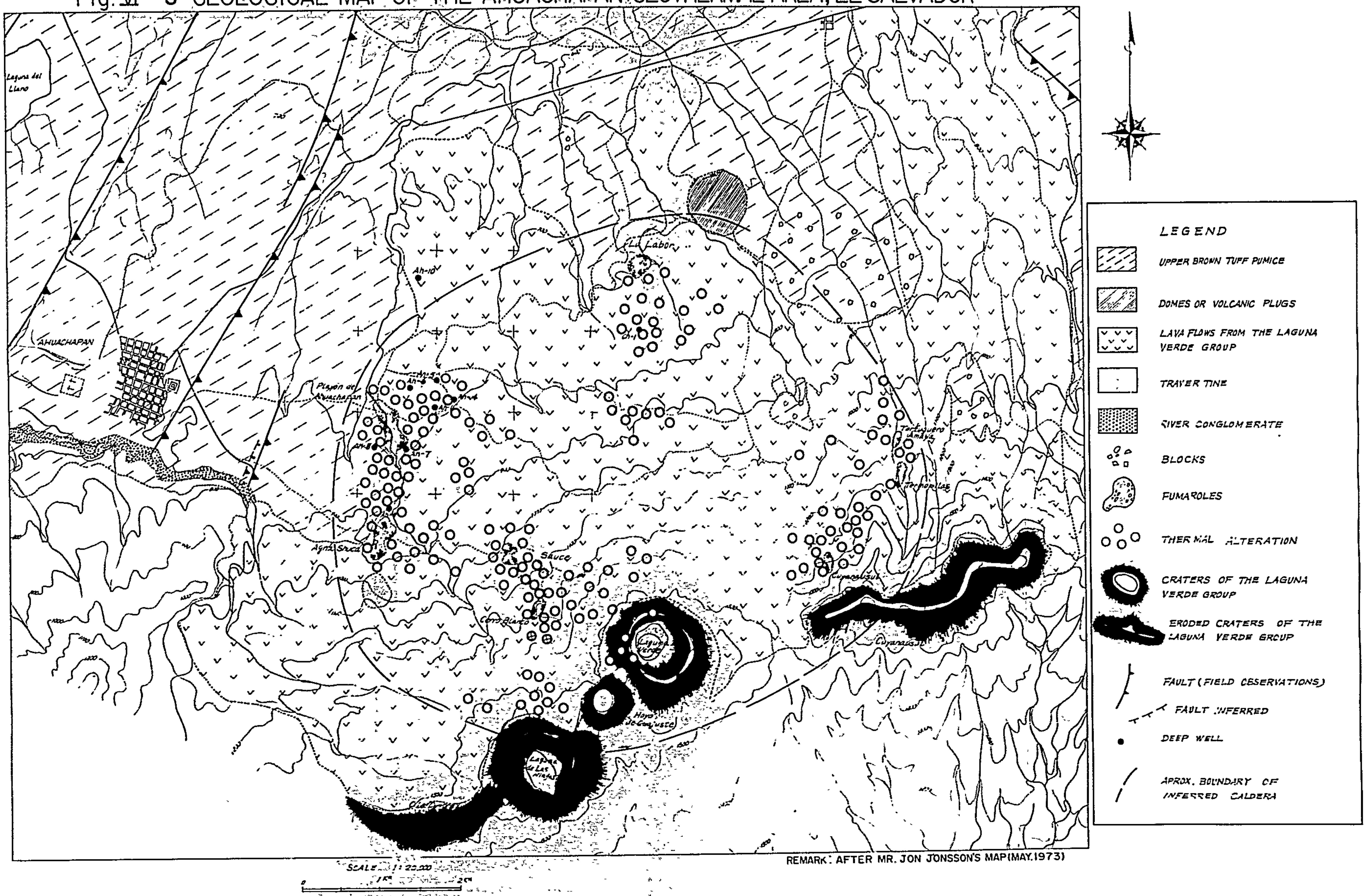


Fig. VI – 8 STRATIGRAPHIC COLUMN



REMARK: COMPILED BY K. WATANABE FROM MR. J. JONSSONS DATA (JUNE, 1973)

Fig. VI - 9 GEOLOGICAL MAP OF THE AHUACHAPAN GEOTHERMAL AREA, EL SALVADOR



REMARK: AFTER MR. JON JONSSON'S MAP (MAY. 1973)

Fig VI-10 SHOWING HIGH PERMEABLE ZONE IN THE DEEP WELLS

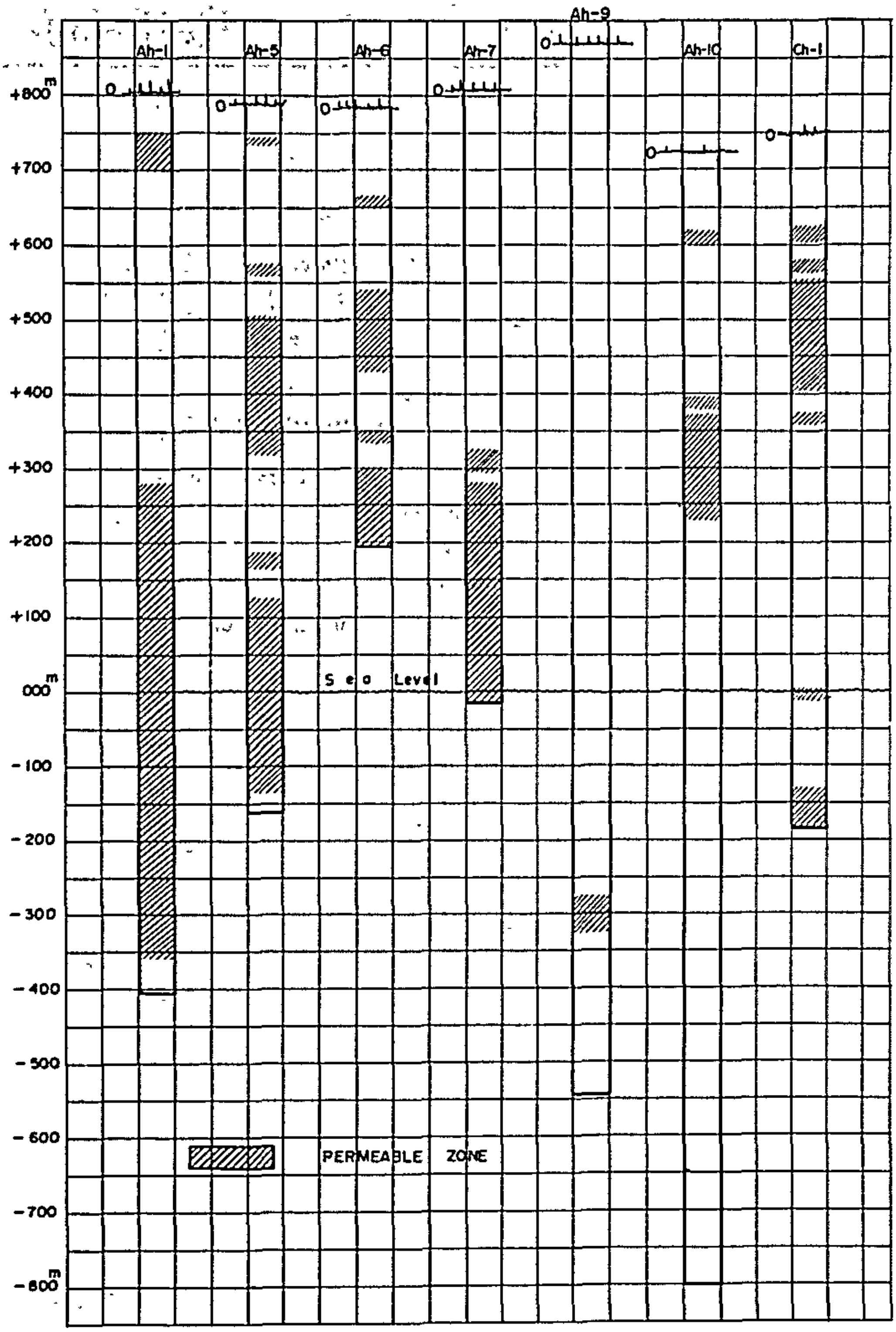
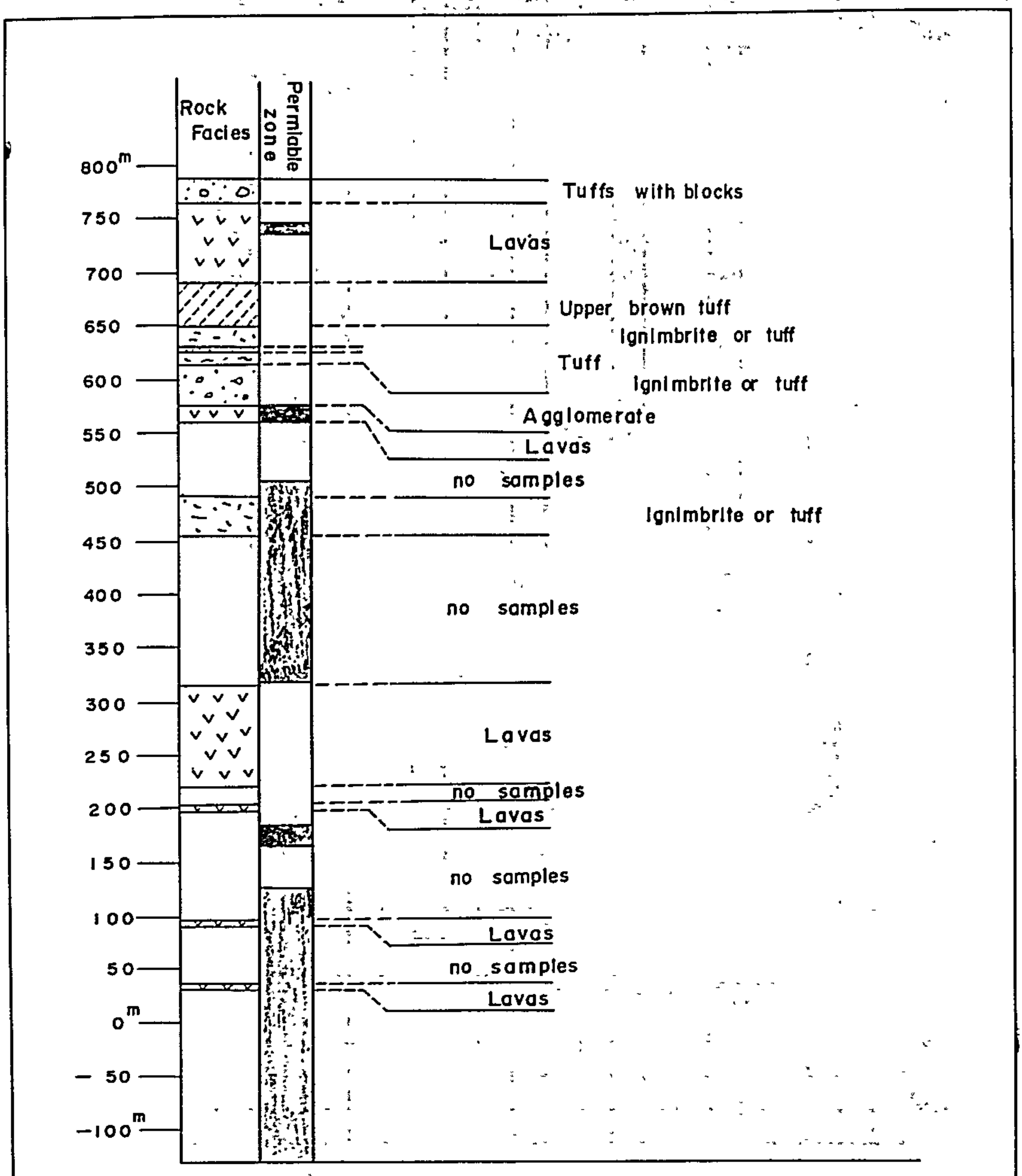
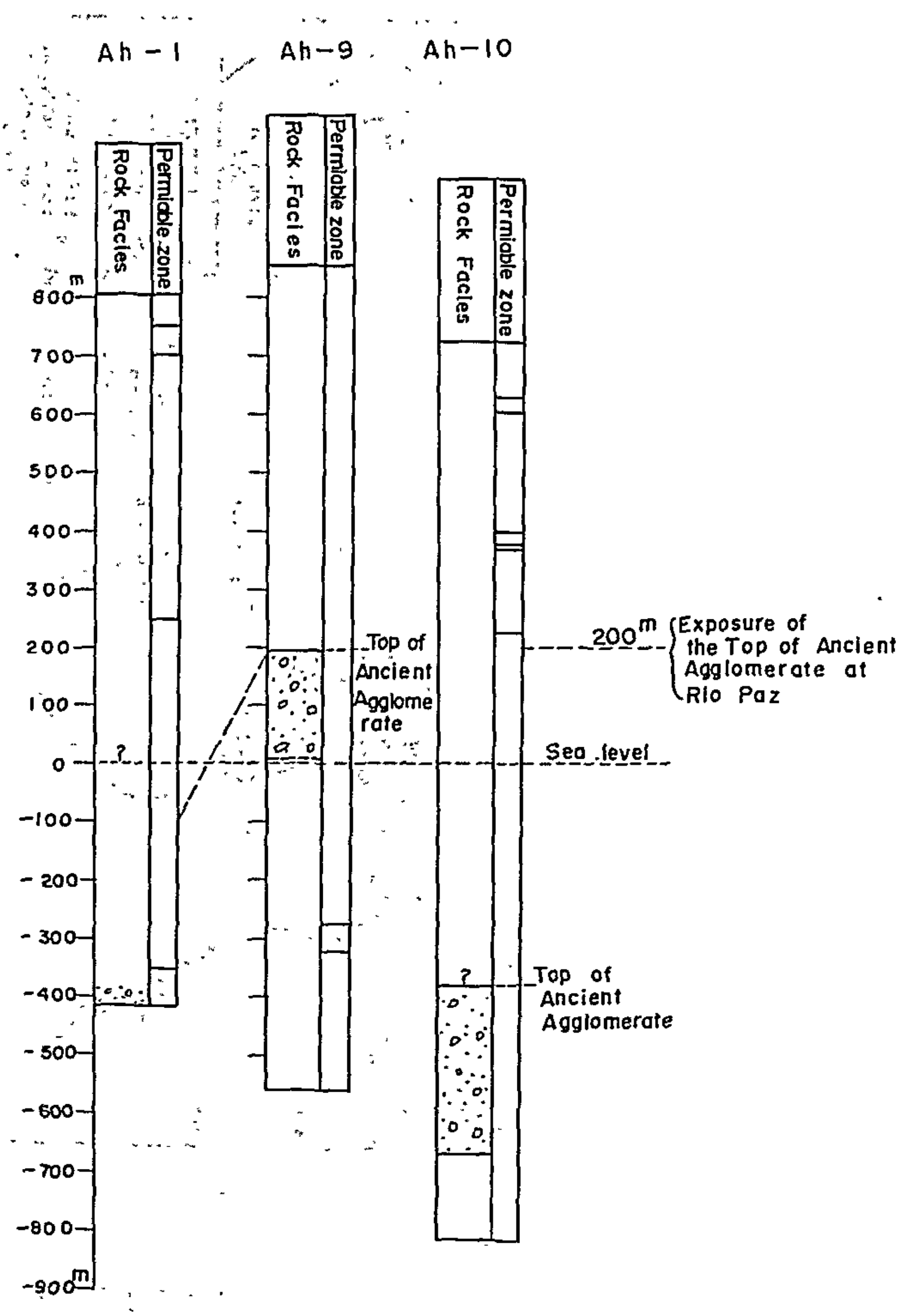


Fig. VI−11 AHUACHAPAN COLUMN NO. 5, DEEP WELL (AH−5)



REMARK: COMPILED BY K·WATANABE FROM MR.J. JONSSON'S DATA (JUNE 1973)

Fig. VI-12 CORRELATION OF AH-1, AH-9 AND AH-10 SHOWS THE TOP OF ANCIENT AGGLOMERATE



REMARK: COMPILED BY K. WATANABE FROM MR.J. JONSSONS DATA (JUNE 1973)

Fig. VI－13 AHUACHAPAN GEOTHERMAL AREA FAULTS INDICATED BY MICROEARTHQUAKE SURVEY

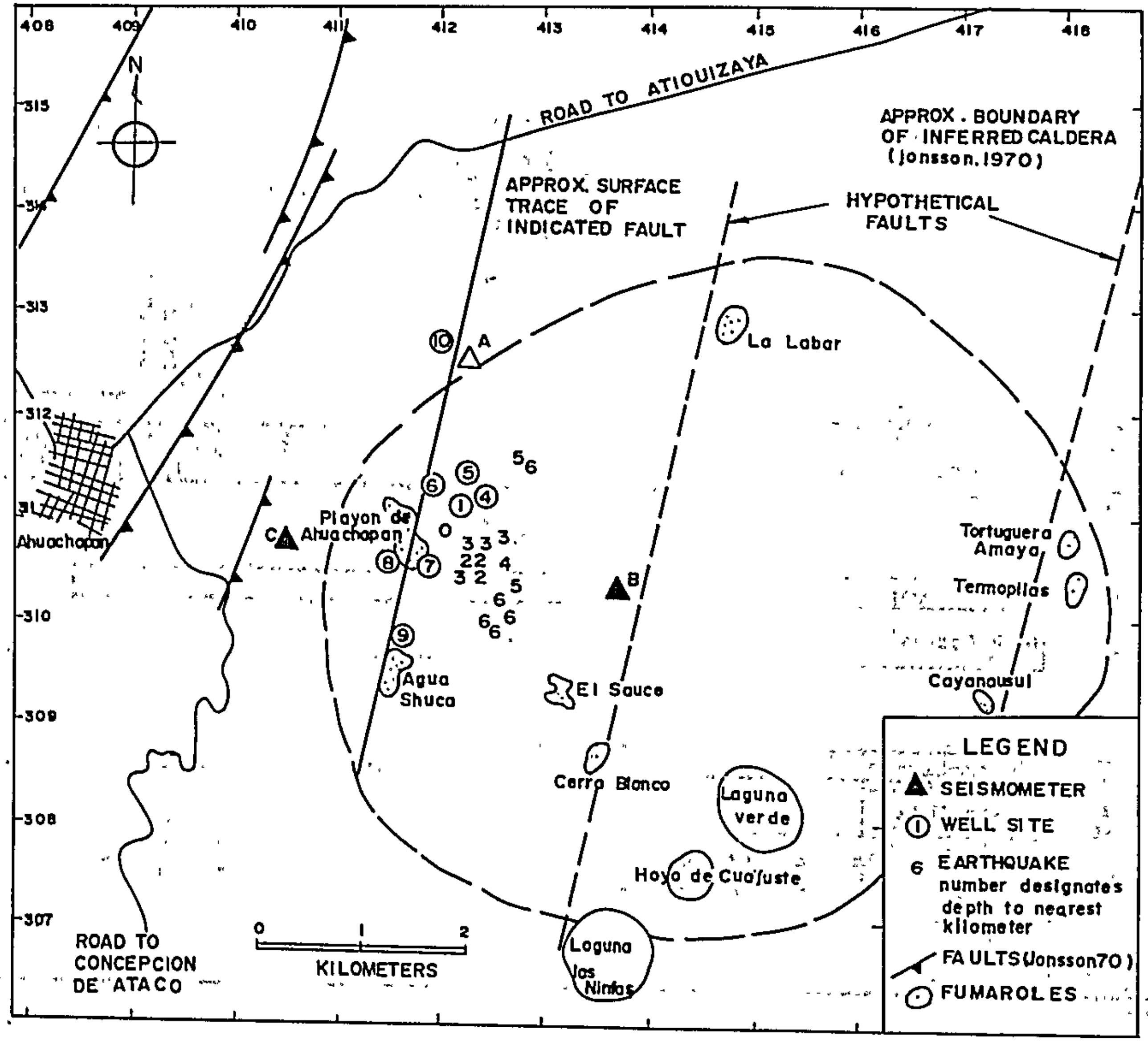


Fig. VI−14 GENERAL GRAPH OF TEMPERATURE

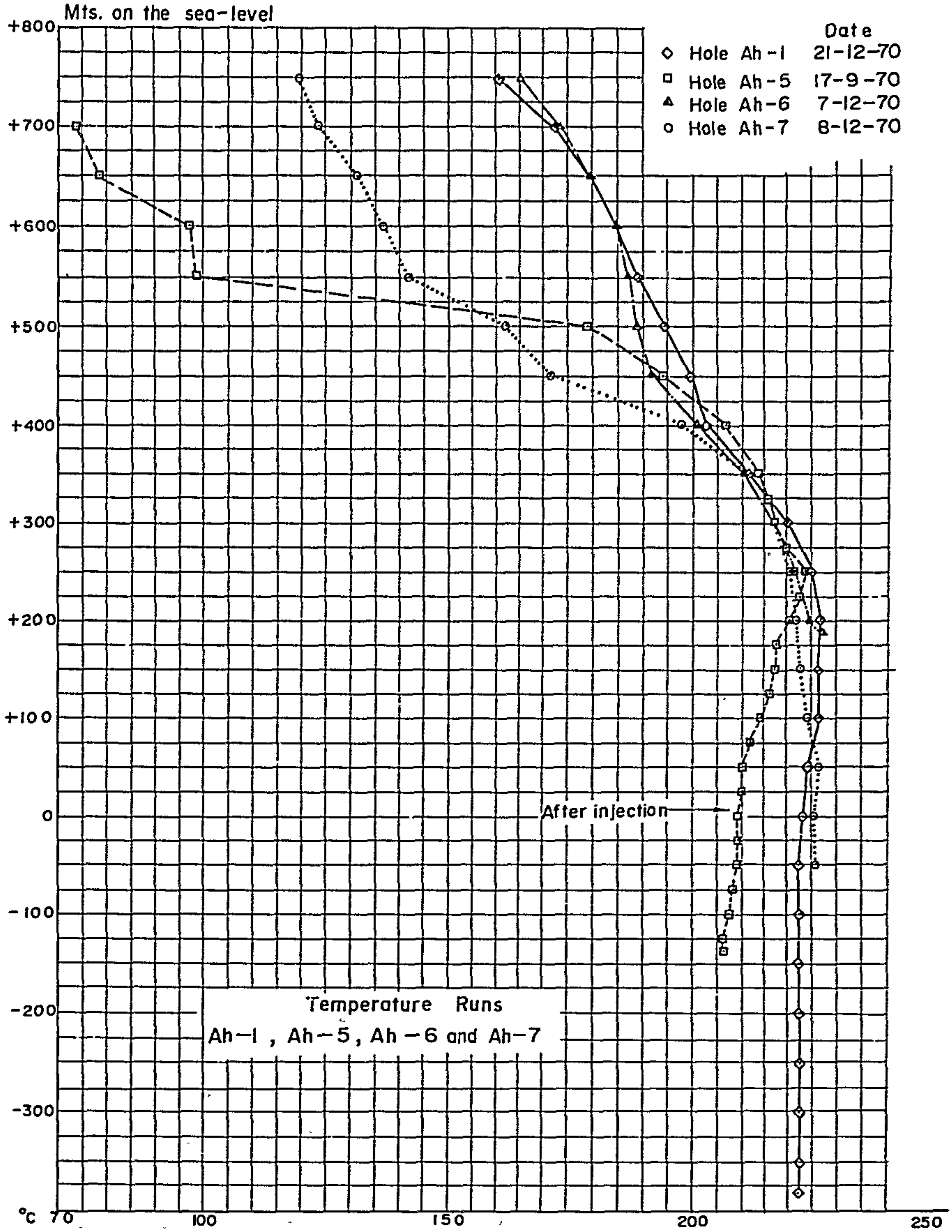


Fig. VI-15 LOCATION OF PROPOSED PRODUCTION AND REINJECTION WELLS

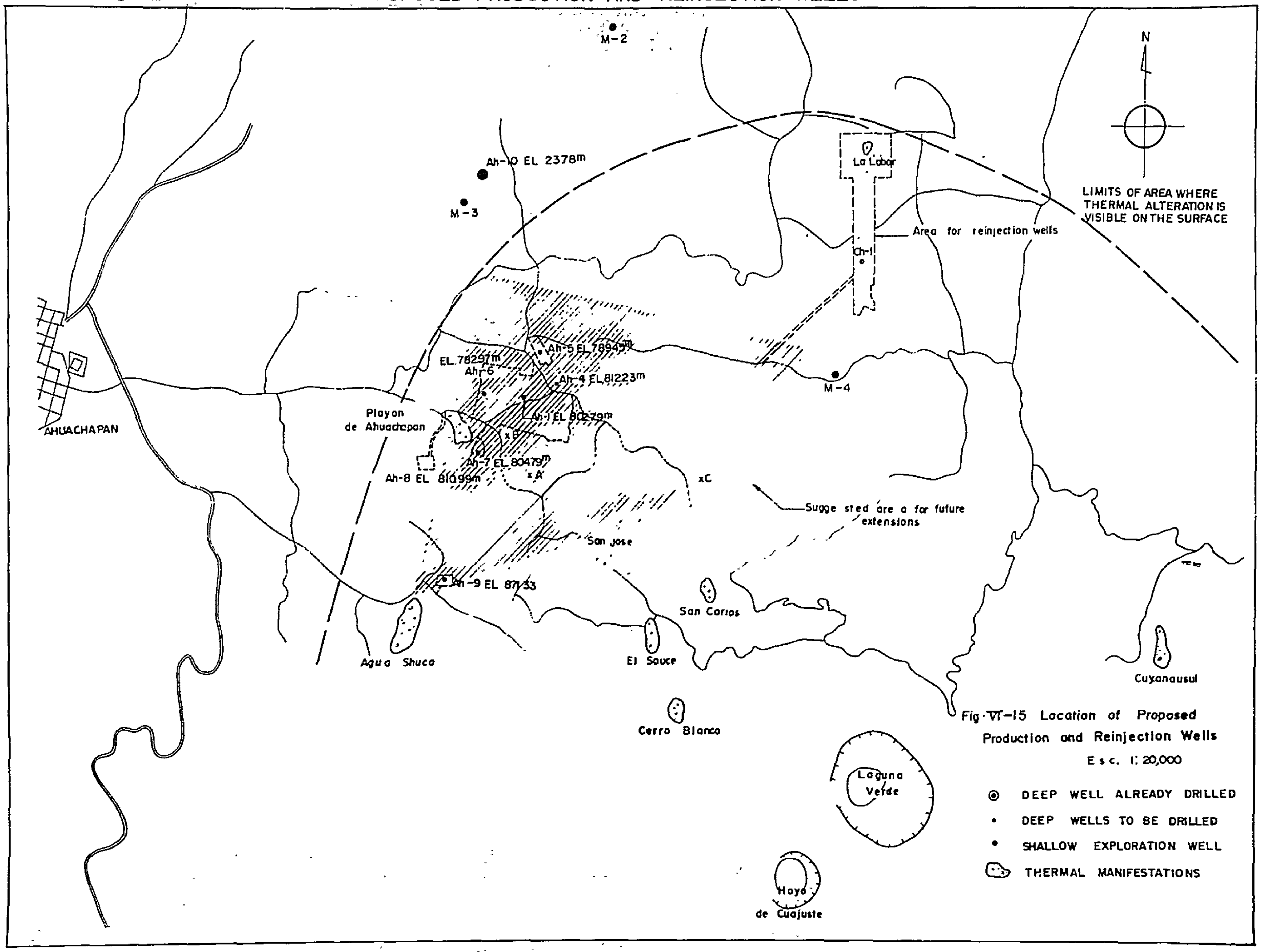
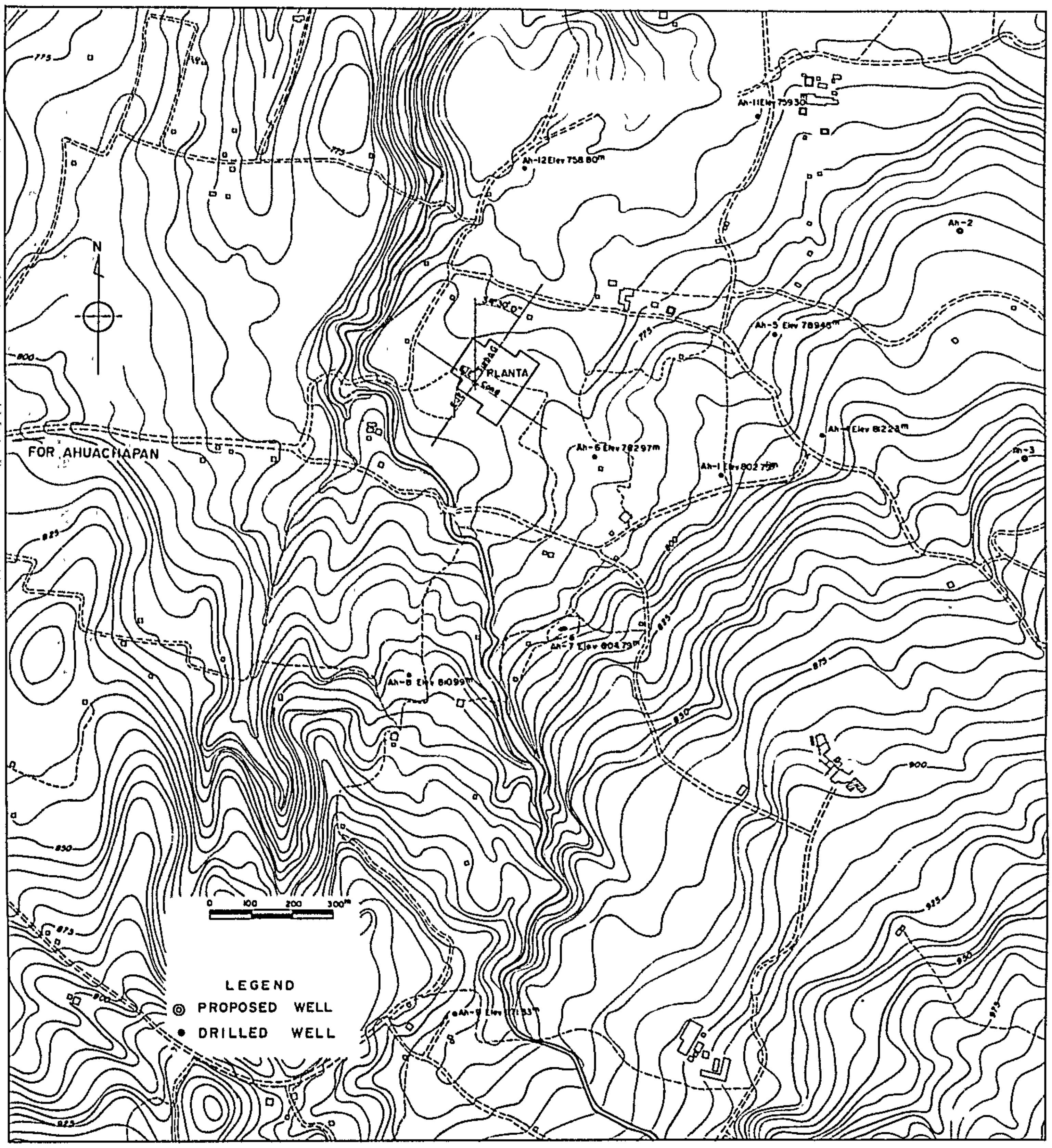


Fig. VI-15 Location of Proposed Production and Reinjection Wells
Esc. 1: 20,000

Fig. VI-16 LOCATION OF WELLS



CHAPTER VII. LOCATION CONDITION

1. Assumption

As no test borings have been made in the Zunil Area, it is not known yet whether the fluid from wells will be steam or a steam-water mixture. However, since there was a greater possibility of a steam-water mixture judging from the present geothermal manifestations, the study was made on the assumption that the fluid in this area is a steam-water mixture as in the area of the Otake Geothermal Field in Kyushu, Japan.

2. Site of Power Plant

The only flat land available as a site of a geothermal power plant in and around the Zunil Area is a tableland approximately 2 km west-south-west of Zunil (around grids 61-34 on the 1/50,000 scale topographical map). This tableland has a shape of the letter "L" along the highway and covers an area of about 125ha.

This land extending over 125 ha is almost flat and the gradient of the maximum slope is about 1/5.

Here, the area of land required for construction of the 1st Stage geothermal power plant must be calculated. It is assumed that the 1st Stage geothermal power plant has an output of 30 MW, turbine inlet pressure of 3.5 kg/cmG and cooling towers of the forced draft type. The power plant premises including a power house, cooling towers and a substation require 1 ha of land. Assuming an output of 3 MW per well and spacing of 150 m between wells, 20 ha of land is required exclusively for wells. Since the 1 ha of land required for power plant premises may be included in the area for wells, the total area required for construction of the 1st Stage 30 MW geothermal power plant is 20 ha.

As a site of the proposed geothermal power plant, 1 ha of land was selected nearly at the center of the tableland (Grid 61:4-34:1 on the 1/50, 000 scale map). Main reasons for this selection are:

(a) The site, being close to the area with geothermal manifestations, is promising for steam production.

(b) The site is not too far from the area expected to be developed in the future.

(c) The site, being close to the highway, is convenient for transportation of equipment and materials.

(d) The site, being approximately 300 m from the main steam of the Samala River in a bee line, is convenient for intake of water. Besides, abundant water resources around the site guarantees supply of water from a nearby branch stream or of underflow water.

The elevation of the site of the proposed geothermal power plant is 2,070 m.

3. Climate

Since no meteorological data were available for Zunil; weather data for the neighboring town of Quezaltenango were used for the study. The annual mean atmospheric temperature is 15.2°C while the maximum atomospheric-temperature is 17.3°C registered in August and the minimum 12.0°C registered in February.

The annual mean humidity is 82%, and the annual precipitation is 915 mm.

4. Water Supply

The requirements for drilling water and house service water are approximately 300 t/h and 30 t/h respectively. This requirement will be easily fulfilled by the supply of water from the nearby Samala River.

5. Access Road

Transportation of machinery and equipment will be easily accomplished by constructing an access road from the nearby highway.

CHAPTER VIII PROPOSED METHODS FOR FUTURE SURVEY

As a result of the preliminary survey, dominant geothermal manifestations were confirmed in the Zunil Geothermal Area, and the concept of the geologic structures and the rising mechanism of the geothermal fluids was grasped. The problems to be clarified were pointed out in detail in the Conclusion and the respective Chapters. The methods of future surveys for further clarification to be made for the development of this geothermal area are proposed in this Chapter. Since the area covering Fumarole Grande and Fumarole Negra seems to be most promising the future surveys will be centered on this area, including overall clarification of the entire Zunil Geothermal Area.

1. Preparation of Topographic Maps

In the present survey, copies of the old edition of the 1/50, 000 scale topographic maps issued by Direction General de Cartografia, Guatemala (D G C) were used, because the new edition was still in the revising process. Consequently, considerable in conveniences were experienced in the determination of locations and recording due to the fact that the maps were not very clear and the highways running through the geothermal area had not been corrected, etc.

Therefore, for more accuracy and higher efficiency of the geologic, physical and chemical surveys to be conducted in the future, more accurate topographic maps of at least a scale of 1/10, 000 or so is necessary. As for the accuracy, enough accuracy will be obtained if the maps plotted from the aerial photos are corrected by the survey results table of the control triangulation stations.

No official discussion has yet been made with the related organizations of Guatemala, but the Team advised some persons in charge of the necessity and asked them to take proper measures. At that time the Team learned that topographic maps of 1/12, 500 scale could be plotted from aerial photos in Guatemala, though this needs reconfirmation.

It is necessary and advisable, therefore, to make contact with the related organization of Guatemala as soon as possible to expedite the preparation of the aerial photos and the topographic maps. These topographic maps, however, are meant just for the next survey, and it needs no mention that local survey maps to meet the purposes of survey will be required in the future when the surveys have progressed.

The aerial photos were furnished by Guatemala for the present survey, among which the photos covering the survey area are within the limit of Fig. IV-2. With these aerial photos, a rough study of geology was made in Japan as described in Section 2, Chapter IV.

As seen in the Figure, however, these aerial photos had been taken presumably for the area from the south of Zunil Village towards the downstream of the Samala River, and the central part of the Zunil Geothermal Area is at the northern limit of these photos. Therefore, for preparation of a topographic map centering on the Zunil Geothermal Area and for interpretation of geology from aerial photos in the next survey, areal photos covering wider areas are necessary.

2. Geologic Survey

By the present survey in a very limited period, the stratigraphy of the Zunil Geothermal Area could be determined predictingly, a geologic map of 1/50,000 scale was prepared, and the structures and mechanism of the geothermal area were observed generally. At the same time, petrigraphy was made with a fairly large number of samples, and the preparation of basic data for the next survey has been completed. In the future, the accuracy of the survey will be raised further, and clarification of remaining problems and completion of a geologic map of the scale of the order of 1/10,000 will be aimed at.

2-1. Zunil Group

The Zunil Group, which makes the main reservoir in the Zunil Geothermal Area, crops out from Cantel on the north towards south along the Samala River, and the thickness confirmed in this section is about 500 m. The upper and lower limit of this group is not known yet. The detailed stratigraphy of this group has to be established by tracing all the outcrops. This stratigraphy makes the basis for the determination of the structures of this area and will serve to the estimation of the nature and location of the cap rock and the reservoir of the underground geothermal zone.

The stratigraphy and thickness below the lowest formation of Zunil Group cropping out at Fumarole Negra to the basement rock cannot be determined on the ground surface of this area. The stratigraphy of this layer is important for the determination of the depth to the basement in this geothermal area.

For clarification of this, the study of the stratigraphy of the Tertiary volcanic rocks around the outcrops of granites distributed in inliers at various places outside the survey area and correlation of them with the Zunil Group are necessary. For this survey, Cajola, Totonicapan and the vicinity of Lake Atitlan are considered to be suitable.

It is expected that if the stratigraphical correlation is made successfully, the depth and structure of the basement in this area would be made fairly clear.

2-2. Cerro Quemado Group

The Cerro Quemado Group near the geothermal area, which had been active from the Tertiary Period until very recently, is important as the thermal source of this geothermal area. The volcanic history of the group deserves further detailed studies. The rhyodacite (Cerro Quemado lava) which forms the domes of various sizes and intrusive bodies in the geothermal area is often directly associated with the geysers, hot springs, fumaroles and altered zones, and it is believed that the intrusion caused developed fissure systems which serve as passages for geothermal fluids. Therefore, the relationship between the occurrence conditions of these rock bodies and the geothermal manifestations needs to be studied in detail. The distribution of these domes and intrusive rock bodies is related with the fault system, and this relationship should also be studied further.

2-3. Geologic Structure

There are two conspicuously developed fault systems, one striking EW - SW and another NE - NNE, and these must be studied in detail. Since dominant thermal source is generally stored in a section between major parallel faults cutting the geothermal area and at the crossing part of two faults, the study of faults makes one of important subjects of study.

As stated in the foregoing section the relationship between the fault system and the volcanic activities also deserves sufficient attention.

3. Survey of Altered Zones

3-1. Field Reconnaisance of Altered Zones

The altered zones has developed well in the dominant geothermal section containing Fumarole Grande and Fumarole Negra in the Zunil Geothermal Area, and are found in various places of the surrounding areas. The results of studies of the samples of altered rocks including clay and soil collected at random revealed alterations generally of the "acid type" and the altered rocks often are silicified rocks containing large quantities of cristobalite and quartz. The existence of silicified rocks suggests deep water lying under the ground.

In the next detailed survey, the altered zones will be classified into the silicified zones of mainly silicified rocks, argillized zones, sulfidized zones, etc. and systematic sampling will be carried out. Each altered zone will be traced closely all over the survey area and its nature, distribution, directionality, etc. will be confirmed, and the relationship between the faults, joints, and fractire zones, that make the passages for the thermal water and steam, and the cracks around the lava domes, and the geologic structures will be studied. Attention will be paid to the difference of degree of alteration according to the difference of the original rocks and they should be discriminated from deuteric alteration and weathering of the original rocks.

3-2. Classification of Altered Zones

The collected samples will be analyzed in detail by the X-ray diffraction analysis, polarized microscope, etc. and the mineral constituents will be determined. And the altered zones traced in the field will be classified further into kaolin zone, alunite zone, cristobalite-quartz.

From the surface distribution of the altered zones, their relationship with the faults as the passages of thermal water will be clarified in more detail and clues will be obtained for the determination of dominant geothermal areas. And it is also possible to estimate, to some extent, the temperature conditions and chemical properties of the deep water that acted on the altered minerals.

When the survey reaches a stage where the cores and slime are obtained and studied by the test boring, the vertical distribution of altered zones in the drill hole can be known. The results can be utilized for estimation of the physicochemical characteristics of the thermal water. For instance, the pH value of the thermal water can be estimated from the combination of altered minerals near the reservoir before the first flow of thermal water.

Further in the future, when it comes to be possible to combine the results of some test borings and the results of surface surveys, the vertical and horizontal distribution of altered zones can be expressed three-dimensionally, and the scale of the geothermal system and the mechanism of rising of thermal water will be clarified gradually. With the increase of the number of test borings, the accuracy of the survey will become higher.

3-3. *pH Measurement of Immersion Solution of Altered Rocks*

In the pH-value contour diagram drawn with the measurements of pH of immersion solutions of altered rocks (Chapter IV-3), there is a general tendency that on the ground surface and near the surface the pH values tends from acidic to alkaline from the passage of thermal water as the center towards the environs, and this is very effective in tracing the rising and movement of thermal water.

In case the deep water is strongly acidic ~ acidic, the pH values of altered rocks on the surface show strong acidity ~ acidity over a wide area. In the vicinity of Aguas Amargas Hot Spring on the southern part of the Zunil Geothermal Area, the pH values are abnormally low and it is feared that the deep water may be strongly acidic (Chapter IV, 3-1). On the other hand, the pH values in Fumarole Grande and the vicinity are 3 ~ 4 and agree with the general tendency of the geothermal areas with neutral ~ weakly alkaline deep water. These results have to be studied in more detail with more samples. Since this test can be made very easily with the use of pH test paper, a comprehensive testing of all the outcrops, cores and slime is advisable.

4. Geophysical Survey

The most conspicuous geothermal manifestations in the Zunil Geothermal Area are seen at both the banks of the Zunil River including Fumarole Grande on the downstream of Zunil Water-fall, and this area will be considered first for the geothermal development. This area is cut by a fault falling on the west with an estimated throw of 100 m along the left bank of the Samala, by which the area is divided into two sections. The geologic conditions necessary for the geophysical survey in this area are summarized in the following.

(1) On the left bank, the lower ~ lowest formation (lower limit unknown) of the Zunil Group (Tertiary volcanic rocks) outcropping in the survey area is distributed and it is anticipated that the granitic basement rocks are relatively shallow, and the depth of the basement rocks must be confirmed.

(2) On the right bank, mostly the middle formation of the Zunil Group outcrops on the bottom of the Zunil and in the southern part, and consequently the basement is deeper than on the left bank. And a very recent lava (mostly blocky and compact near the bottom) of an estimated thickness of 100 ~ 150 m covers the Zunil Group and forms a wide plateau.

(3) Rhyodacite intrudes along the NE fault forming a small dome on the east of Zunil Water-fall. Therefore, the main purpose of the geophysical survey is to determine the depth of the basement, location of the faults and their throws.

The proposed survey items, including other problems, are summarized in Tables VIII-1 and VIII-2. For these geophysical surveys, it seems topographically difficult to carry out the survey traverses for the seismic survey and the resistivity survey accross the deep valley of the Samala River, but as shown in Fig. VIII-1, it seems possible on the right bank to establish the survey traverses along the Pachamiya River, along its tributary on the south or utilizing the road to Fuentes Georginas as much as possible, so that the variation in elevation may be as small as possible.

The problem is whether the expected results can be obtained by the geophysical surveys in a location of this topography and geology. Opinions of geophysical prospecting specialists are as follows.

(1) If the purpose of survey is to grasp the differences of geologic structures on both the banks, sufficient results are expected by the survey traverses as shown on Fig. VIII-1.

(2) Instead of a single method, more than two methods of geophysical surveys should be adopted, and the results of surveys should be analysed together with the results of geological surveys, by which expected results will be obtained.

(3) Since the survey area has been limited by the present preliminary survey to a relatively small area, the joint use of the common depth point horizontal data staking method, 4-hold of the seismic survey and the resistivity vertical survey method would be most adequate from the view point of economy, speediness in utilization of the results for development planning, and effectiveness of the survey results. However, there might be difficulty in the detection of reflection waves according to the degree of alteration and fractures of the supposed basement granites.

Even though these methods involve the foregoing problems, these methods of geophysical survey are proposed from the experiences in Japan and Ahuachapan where the seismic survey or the resistivity survey or the combination of both was very effective in successful selection of test boring locations.

5. Geochemical Survey

The geochemical preliminary survey in Guatemala revealed that samples containing deep water suggesting aquifers underground could not be obtained excepting at the geyser in Zunil Geothermal Area, and in San Marcos and Amatitlan Geothermal Areas. Therefore, it is proposed to adopt intensively the survey methods of the steam system for fumarol areas instead of the method of the hydrothermal system. (Conclusions and Chapter V, 2)

Especially, before the deep water is obtained by boring, it would be most effective and advisable to put emphasis on the fumarolic steam and altered rocks (soil) abundantly available in Zunil and Moyuta Geothermal Areas, and an intensive and systematic detailed survey is recommended. The survey method of the steam system is being developed by KOGA, member of the Survey Team, and if this method is applied in Guatemalan Geothermal Area, it would make the first application in the world.

5-1. Measurement of Hg in Altered Rocks

The measurement of Hg in the altered rocks is considered to be the most effective method of survey for the steam system. The measurement is relatively simple, and by handling many samples, it is possible to pinpoint the high temperature part of the geothermal area.

The basic experiments for this method is now in progress. For example, when altered rocks are heated, the Hg in it disappears very rapidly at 100 ~ 150°C, and this disappearance is not conspicuous below 100°C. (KOGA et al. to be published) In other words, it indicates that Hg is carried to the surface in fumarolic gas in proportion to the heating temperature under the ground, and is cooled suddenly near the surface and deposited or absorbed in the altered clay, hot spring deposits, etc.

5-2. Analysis of Condensed Water from Fumarolic Steam

This is the method of tracing the high temperature parts of the geothermal area by the measurement of the volatile components of B, F, NH_4, Hg, etc. Especially, the measurement of Hg which is most easily vaporized, is of the greatest interest. This method will prove effective, because a very sensitive measurement (0.0001 ppm) can now be made by the advancement of analytical equipment.

5-3. Analysis of Fumarolic Gas

At present, results of analyses of fumarolic gases are not positively utilized in prospecting. The fumarolic gases, however, reflect the underground conditions and transmit much information to the surface. The gas concentration, the CO_2 and H_2S concentrations and the CO_2/H_2S ratio indicate the characteristics of the thermal water. (KOGA and NODA, 1973) The analysis makes it possible to anticipate possible troubles due to calcaceous sinter in the geothermal power generation.

It is necessary to select adequate fumaroles and it needs paper sampling technique to prevent air from mixing into, but many analyses should be made with major fumaroles at least.

5-4. Measurement of Isotopes in Hot Spring Water

By measuring Tritium (H_3), Deuterium (D) and Oxygen-18 (^{18}O), constituents of hot spring water itself, and comparing them with the surface water, the age, history, temperature, etc. of the hot spring water can be determined. It is also possible to presume the mode of formation of the hot spring by the measurement of ^{34}S.

5-5. Measurement of Total Output

In the Zunil Geothermal Area, there spring out many hot springs widely at various places, and these hot spring water flows into the Samala River. Thus it is possible and necessary to calculate the total output of chemical constituents coming out of all the hot springs in the area by analyzing the samples taken at the predetermined points on the Samala and at the junctions of the tributaries.

6. Test Boring

In the Zunil Geothermal Area, the boundary layers between the Zunil Group and the basement granitic rocks covered by the former in unconformity relations, seem to be most promising as the geothermal reservoir. However, the Zunil Group in this area below the lowest formation confirmed by the outcrops lie concealed under the ground, and there is no way of actually confirming the depth of the basement, detailed stratigraphy and thickness of Zunil Group, and its relationship with the basement, except by the test boring. By the test boring, the distribution and characteristics of the thermal water and the temperature gradient can be actually observed.

Even though recently the prospecting technique (physical, chemical and geologic) has advanced remarkably, and has come to have high accuracy, it is no exaggeration to say that the real appraisal and development program of the geothermal area near the conclusion only through the test boring. In the Zunil Geothermal Area, too, sincere request is made of the related authorities to continue the surveys aiming at the materialization of test borings.

The type, depth, number of borings required, etc. have to be studied in more detail, but it is desirable to adopt the core boring as much as possible, for the determination of the depth of the basement and the stratigraphy of the Zunil Group. It is very difficult to determine the necessary depth of boring from the results of the present preliminary survey, but it may daringly be said that test borings of about 1,000 m may produce expected results.

Opinions differ as to the time of test borings, but since the analitical effects of geophysical survey are enhanced by the boring cores (or logging), it is advisable that the test borings are carried out as soon as possible.

7. Survey Items for Power Plant Design

7-1. Meteorological Observation

The following meteorological observation should be started on the proposed Zunil Power Plant Site from 2 years before the start of power plant design.

(1) Wind direction and velocity:	To be continuously recorded by an automatic recorder
(2) Humidity:	To be recorded once a day
(3) Atmospheric temperature:	Ditto
(4) Precipitation:	Ditto

7-2. Hydrographic Survey

(1) Flow measurement:	Once a week
(2) Water temperature measurement:	Ditto
(3) Water quality analysis:	Once in 3 months

7-3. Test of Well Characteristics

After production wells are completed, the following measurements should be carried out once in 3 months.

(1) Steam flow

(2) Hot water flow

(3) Gas content

(4) Chemical composition of gas

(5) Chemical composition of steam

(6) Chemical composition of hot water

7-4. Materials Tests

The materials intended for use in the power plant should be tested in the steam and hot water from the wells, starting from 1 year prior to the start of design of the power plant, for selection of suitable materials.

7-5. Soil Nature Test

Before the start of the power plant design, the geology and soil bearing capacity of the site must have been studied.

TABLE VIII-1. PLAN OF GEOPHYSICAL EXPLORATION IN ZUNIL GEOTHERMAL AREA

Type of Survey	Purpose	Method of Survey		Traverses Plan	Priority
1) Seismic Survey on both banks of the Samala including Fumarole Grande and Fumarole Negra (Refraction and reflection method).	1) Confirmation of depth to the basement granites and the presumed NE fault falling on the NW.	Refraction Method	1) Traverse lines of Max. 3 km can be established in the area, with which the surveyable depth is presumed to be 300 m. If distant shot points can be established on the extension of the traverse line, the surveyable depth can be extended. 2) If compact and hard high-speed layers lie on the upper part, the refraction method is not suitable. On the right bank of this area the altered zone is covered with about 100 m thick blocky Zunil Water-fall lava, and its effect must be taken into consideration.	The traverse lines for the method will be used commonly. Aside from shot holes for the reflection method, shot holes for refraction method need to be prepared on both ends of traverse lines.	1
		Reflection Method (common depth point horizontal data staking method, 4-hold)	1) Exploration of deep structures in possible with shorter traverse lines. 2) Common depth point horizontal data staking method of high S/N ratio is effective. 3) Detection of reflected horizon is difficult when the depth of basement is smaller than 300 m. In such cases, the refraction method will be resorted to, or both method will be used jointly.	Length of traverse lines 4 traverse lines : 6.5 km Number of shot points : 65 Interval of receiving points : 25 m Interval of shot points : 75 m	
2) Resistivity survey (vertical method) by common use of traverse lines of seismic survey.	2) Location of reservoir in Tertiary volcanic rocks (Zunil Group), and distribution of altered zones.	Resistivity Survey (vertical method)	1) Because of big difference of resistivities between the altered zone and the upper and the lower layers, the low resistivity band corresponding to the altered zone can be detected. It is reported that the resistivity method was very effective in locating test boring holes in Ahuachapan Geothermal Area. 2) In case thick low resistivity layers of high porosity are distributed near the surface, the analysis of survey result is difficult.	Schlumberger elctrode arrangement 4 traverse lines : 12.5 km Number of survey points : $\frac{AB}{2}$ = 1,000 m, 22 points $\frac{AB}{2}$ = 750 m, 8 points	1

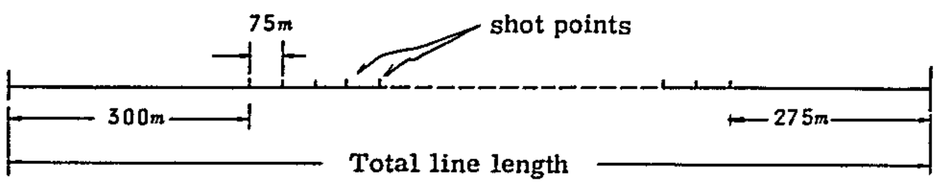
Type of Survey	Purpose	Method of Survey		Traverses Plan	Priority
3) Gravity & magnetic general survey	3) Supplementary to seismic method; survey of geologic structure on both banks of the Samala	Gravity Method	1) Gravity method is effective for grasping general tendency of underground structures over wide areas. 2) Wide area survey including the surrounding areas is necessary for the survey of structures of geothermal areas. 3) In case high specific gravity rocks are distributed thick in the upper layers, the analysis of deep structures is difficult.	Survey points : 5 km x 5 km 16 points/km^2 Survey points in surrounding areas : 15 km x 15 km 3 points/km^2	2
		Magnetic Method	1) Magnetic method is effective for the survey of degree of alteration near the surface, and a higher effect is expected when used together with the gravity method. 2) However, this method is not suitable for survey of distribution of deep altered zones.	Same as above.	

TABLE VIII-2 SEISMIC SURVEY (Common Depth Point Horizontal Data Staking Method, 4-Hold)

Location		Traverse line length*		Number of shot holds & depth
Right Bank	Parallel with the Samala (N-S direction)	A	2,225 m	10 m x 23 holes = 230 m
	Crossing A-line (E-W direction)	B	1,250 m	10 m x 12 holes = 120 m
Left Bank	Along the Pachamiya (E-W direction)	C	1,550 m	10 m x 16 holes = 160 m
	Along tributary of the Pachamiya (E-W direction)	D	1,475 m	10 m x 13 holes = 130 m
Total		4 lines	6,500 m	10 m x 64 holes = 640 m

Note: Traverse line plan may be changed to meet the topography.

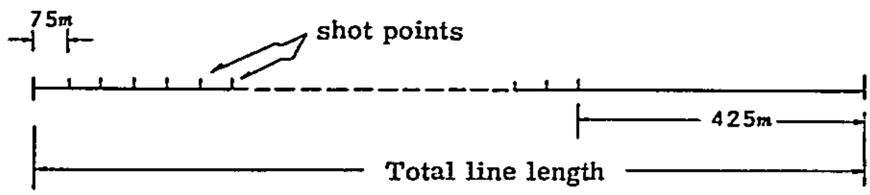
* A, D Traverse Line Plan



Interval of shot points ———— 75 m

250 ~ 300 m lines are added on both ends of traverse lines.

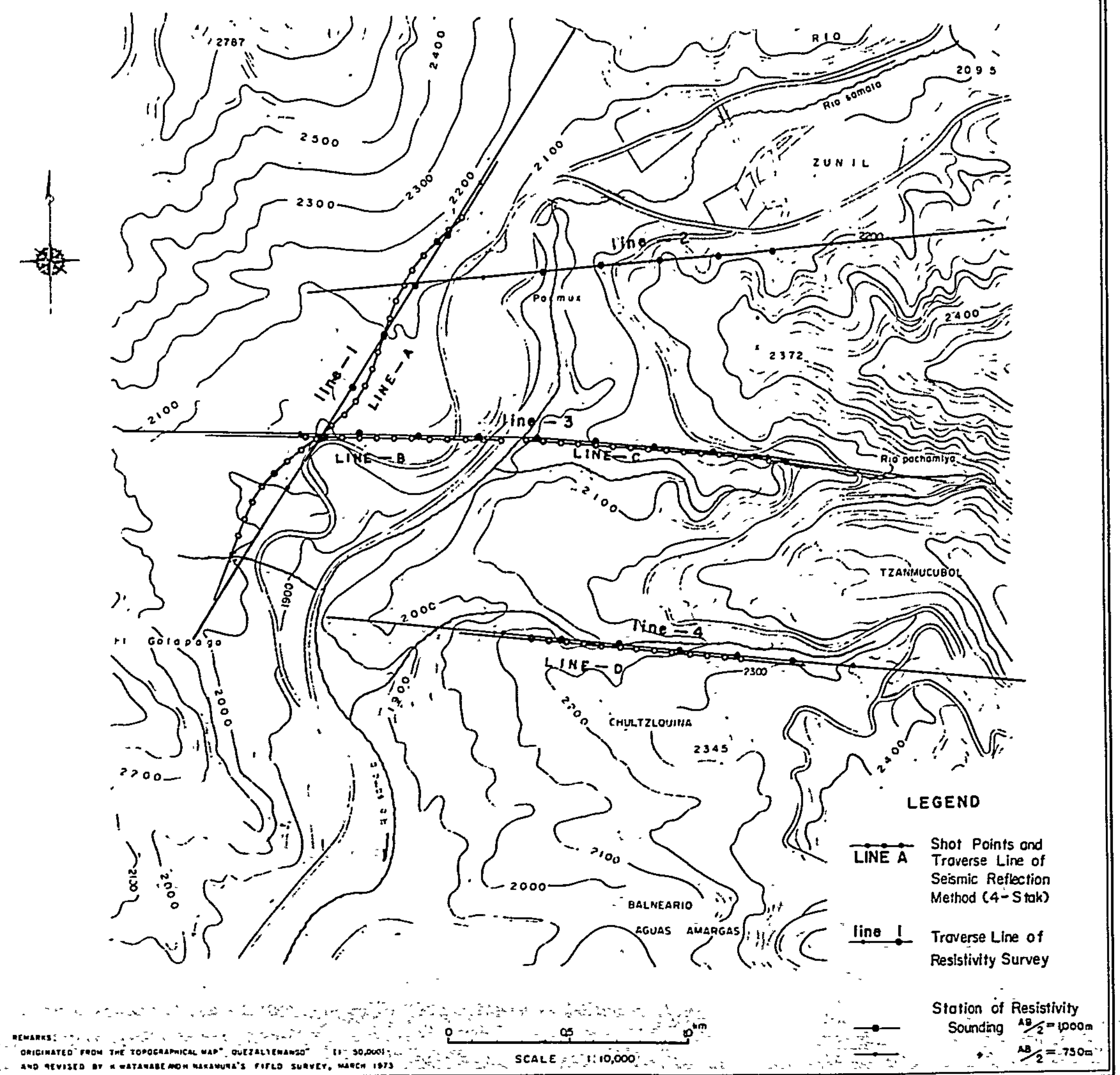
* B,C Traverse Line Plan



Interval of shot points ———— 75 m

425 m line is added on one end of traverse lines.

Fig.VIII-1 MAP SHOWING OUTLINE OF SEISMIC REFLECTION AND RESISTIVITY SURVEY TRAVERSES



CHAPTER IX POWER SITUATION AND BASIC PLAN OF GEOTHERMAL POWER PLANT

1. Power Situation

1-1. Present Power Supply-demand Situation

Data on power supply-demand situation for a period of 15 years from 1957 to 1971 are available.

The installed capacity increased five folds from 29.2 MW in 1957 to 162.4 MW in 1971. During the same period, the generated energy increased five times from 124.4 million KWh to 606.2 million KWh. Until 1964 the Guatemala Electric Company (Empresa Electrica de Guatemala) was the only power company in the country, but power generation by INDE began in 1965 and at present INDE produces more than half of the total generation.

The maximum power demand increased about four times from 28.5 MW in 1957 to 119 MW in 1971, and the load factor also increased steadily from 49.8% to 58.2%. The composition of power demand which was 42% for domestic use, 33% for industrial use, 15% and 14% respectively, showing a sharp increase for industrial use.

1-2. Power Supply-demand Forecast

Power supply-demand forecast for a 15 year period from 1975 to 1989 is as follows.

Annual power demand is expected to increase from 1,052 million KWh in 1975 to 4,937 million KWh in 1989, while generation is expected to increase from 1,209 million KWh to 5,610 million KWh during the same period. An annual increase rate of 12% ~ 10% is expected.

1-3. Power System

The power system of this country comprises three systems -- Central System, the Eastern System and the Western System. The Eastern System and the Central

System are interconnected by 66 KV transmission lines but the Western System is an independent system.

The system voltages are 138 KV and 66 KV for the Central System, 66 KV and 33 KV for the Eastern System and 50 KV for the Western System.

1-4. Power Generating Facilities

The four existing hydroelectric power stations owned by INDE have a total installed capacity of 89 MW and an annual generation of 330 million KWh.

The two existing thermal power stations owned by EEG (Guatemala Electric Co.) have a total installed capacity of 30 MW and an annual generation of 200 million KWh. Three more units are scheduled to be constructed at Escuintla by 1976 under INDE's plan and they are expected to have a total installed capacity of 133 MW and an annual generation of 1,240 million KWh.

Two gas turbine power stations, each owned by INDE and EEG, have a combined installed capacity of 37.5 MW are an annual generation of 90 million KWh.

The two existing diesel power stations owned by EEG have a total installed capacity of 9 MW and generate 9 million KWh annually.

The total installed capacity of power generating facilities in the country is expected to reach 298 MW by 1976 and the annual generation in the same year is estimated at 1,669 million KWh.

2. Basic Plan of Geothermal Power Plant

2-1. Potential

As previously mentioned, the only flatland available for development among areas with geothermal manifestations is located approximately 2 km west-southwest of Zunil and covers an area of 125 ha. Wells can be drilled at any point within this area.

Since the drilling of wells of the steam-water mixture type requires intervals of 150 m, the area required for one well is 2 ha.

Therefore, this site is sufficiently large enough for drilling more than 60 production wells. Assuming on 80% efficiency, a total of 50 production wells may be drilled. Assuming an output of 3 MW per well, the potential of this area is estimated at about 150 MW.

2-2. Rated Output of 1st Stage Geothermal Power Plant

Steam conditions such as steam flow and pressure cannot be determined until the discharge from drilled steam wells is actually measured. The only thing that can be said generally is that steam wells of low output is expected from shallow basement rocks, but there is a greater possibility of steam wells of higher capacities from deep basement rocks.

Since exploration has not been made in the area, definite conclusions cannot yet be drawn. Nevertheless, a basic plan of the 1st Stage geothermal power plant has been worked out on the following assumptions.

2-2-1. Rated Output

The rated output of the 1st Stage geothermal power plant is assumed to be 30 MW. This is the minimum unit size of economically feasible power generation.

2-2-2. Well Output

Well output per production well is assumed to be 3 MW on an average.

2-2-3. Turbine Inlet Pressure

Turbine inlet pressure is assumed to be 3.5 kg/cm^{2}G (saturated steam).

2-3. Basic Plan

2-3-1. Basic Policy

(1) The primary object is to develop economical and safe power generating facilities.
(2) Generating cost will be equivalent or lower than that of a latest thermal power plant.
(3) Heat cycle will be simplified as much as possible.
(4) The proposed power plant will be planned as a complete base load power plant with a plant factor of more than 90% and high reliability.

2-3-2. Generating Cost

The generating cost shall be competitive with the generating cost of a modern large capacity oil firing thermal power plant. Since the most part of the generating cost of a geothermal power plant is proportional to the cost of construction, facilities shall be simplified as much as possible to hold construction cost down.

2-3-3. Output

The rated output will be 30 MW and the overload capacity will be 39 MW (an increase of 30%). The size of capital investment for the 1st Stage is to be determined on the basis of the estimated total final output of 130 MW, comprising 30 MW for the 1st Stage, 50 MW for the 2nd Stage and 50 MW for the 3rd Stage.

2-3-4. Generating System

Condensing steam turbine power generation with direct use of natural steam by wellhead separation.

2-3-5. Operation of Power Plant

Facilities will be operated (starting and stopping) with a minimum number of operators.

2-3-6. Buildings

A compact and simple indoor type power house will be provided. An office room, a warehouse and oil storage will also be provided.

2-3-7. Layout

The power house and the cooling tower are arranged in parallel and a condenser is located in-between. The steam receiver which collects steam from steam wells is located on the opposite side of the power house to the condenser. The outdoor substation is located at the north end so as to make the installation of outgoing transmission lines easier. Extension of the substation in the 2nd Stage and the subsequent stage is planned on the west side.

2-3-8. Steam Wells

A total of 10 steam wells will be arranged around the 1st Stage power plant at intervals of 150 m. The final diameter of a steam well will be $8^{5}/8$".

2-3-9. Wellhead Equipment

(1) A bottom outlet cyclone steam water separator will be installed at each well.
(2) A silencer will be installed at each well. This silencer will be equipped with a steam flow measuring instrument for periodic measurement of steam flow.
(3) A gas sampling nozzle will be installed on the wellhead piping for periodic measurement of the amount and ingredients of gas.

2-3-10. Steam Transmission Lines

(1) Discharged steam will be separated at wellhead and transported to the power plant in single phase steam.
(2) The steam transmission lines will be installed on the ground for economy, and as many manifolds as possible will be utilized.
(3) A steam receiver will be provided near the power house.

2-3-11. Machinery and Equipment

(1) The turbine will be of the single flash condenser type.
(2) The condenser will be of the barometric jet type.
(3) A steam ejector will be used as gas extractor.
(4) The cooling water will be cooled and recirculated by the mechanical forced cooling tower. For cooling water makeup, the total amount of condensate will be used, and the supply from outside sources will be limited to a minimum.

Table IX-1 Electric Power Situation in Guatemala (1957 - 1971)

Item \ Year	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Power Source (MW)															
Thermal	7.0	7.0	18.5	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Diesel	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Gas Turbine	—	—	—	—	—	—	—	12.5	25.0	25.0	25.0	37.2	37.2	37.2	37.2
Heat Sub-total	16.0	16.0	27.5	39.0	39.0	39.0	39.0	51.5	64.0	64.0	64.0	76.2	76.2	76.2	76.2
Hydraulic	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	26.2	26.2	26.2	26.2	86.2	86.2
Total	29.2	29.2	40.7	52.2	52.2	52.2	52.2	64.7	77.2	90.2	90.2	102.4	102.4	162.4	162.4
Generation (10^6KWH)															
Thermal	40.2	45.5	70.3	98.0	140.4	164.7	203.7	216.7	245.8	238.7	231.7	235.5	256.5	199.7	248.3
Diesel	12.3	23.8	21.4	7.6	3.6	4.8	6.1	12.9	14.0	12.9	13.8	15.0	14.5	18.3	3.4
Gas Turbine	—	—	—	—	—	—	—	9.5	36.6	71.9	84.2	119.0	134.4	78.4	79.0
Subtotal-Thermal	52.5	69.3	91.7	105.6	144.0	169.5	209.8	239.1	296.4	323.5	329.7	369.5	405.4	296.4	330.7
Hydro	71.9	74.6	73.6	79.1	66.7	69.5	64.1	67.1	64.6	83.5	106.1	105.5	125.8	278.5	275.5
Total	124.4	143.9	165.3	184.7	210.7	239.0	273.9	306.2	361.0	407.0	435.8	475.0	531.2	574.9	606.2
Composition of Power Sources (10^6KWH)															
Guatemala Electric Company	124.4	143.9	165.3	184.7	210.7	239.0	273.9	306.2	354.0	348.0	332.8	286.0	312.1	256.8	269.2
I. N. D. E.	—	—	—	—	—	—	—	—	7.0	59.0	103.0	189.0	219.1	318.1	337.0
Maximum Power (MW)	28.5	30.0	37.2	41.0	45.5	50.8	56.9	65.6	76.0	85.9	88.3	94.1	105.0	115.9	119.0
Load Factor (%)	49.8	54.8	50.7	51.3	52.9	53.7	55.0	53.1	54.2	54.1	56.4	57.6	57.9	56.6	58.2
Demand (10^6KWH)	105.9	122.5	139.0	154.9	176.7	199.8	229.9	260.1	306.7	348.7	376.9	411.9	460.7	502.0	531.8
Loss (%)	14.9	14.9	15.9	16.1	16.1	16.4	16.0	15.0	15.0	14.3	13.5	13.5	13.3	12.7	12.3
Composition of Demand (%)															
Residential	42	41	41	42	40	39	36	34	32	31	31	30	30	29	30
Industries	33	35	35	33	34	34	38	40	41	42	41	41	41	42	41
Commercial	15	15	15	15	16	15	14	14	14	14	15	15	15	15	15
Autonomous Bodies	3	3	4	5	5	8	8	9	9	9	9	10	11	11	11
Government	7	6	5	5	5	4	4	3	4	4	4	4	3	3	3
Annual Growth Rate (%)															
Demand	—	5.1	24.2	10.0	11.1	11.6	11.9	15.4	15.8	13.0	2.8	6.6	11.6	8.3	2.7
Generation	—	15.7	14.9	11.7	14.1	13.4	14.6	11.8	17.9	12.7	7.1	9.0	11.8	9.0	5.4

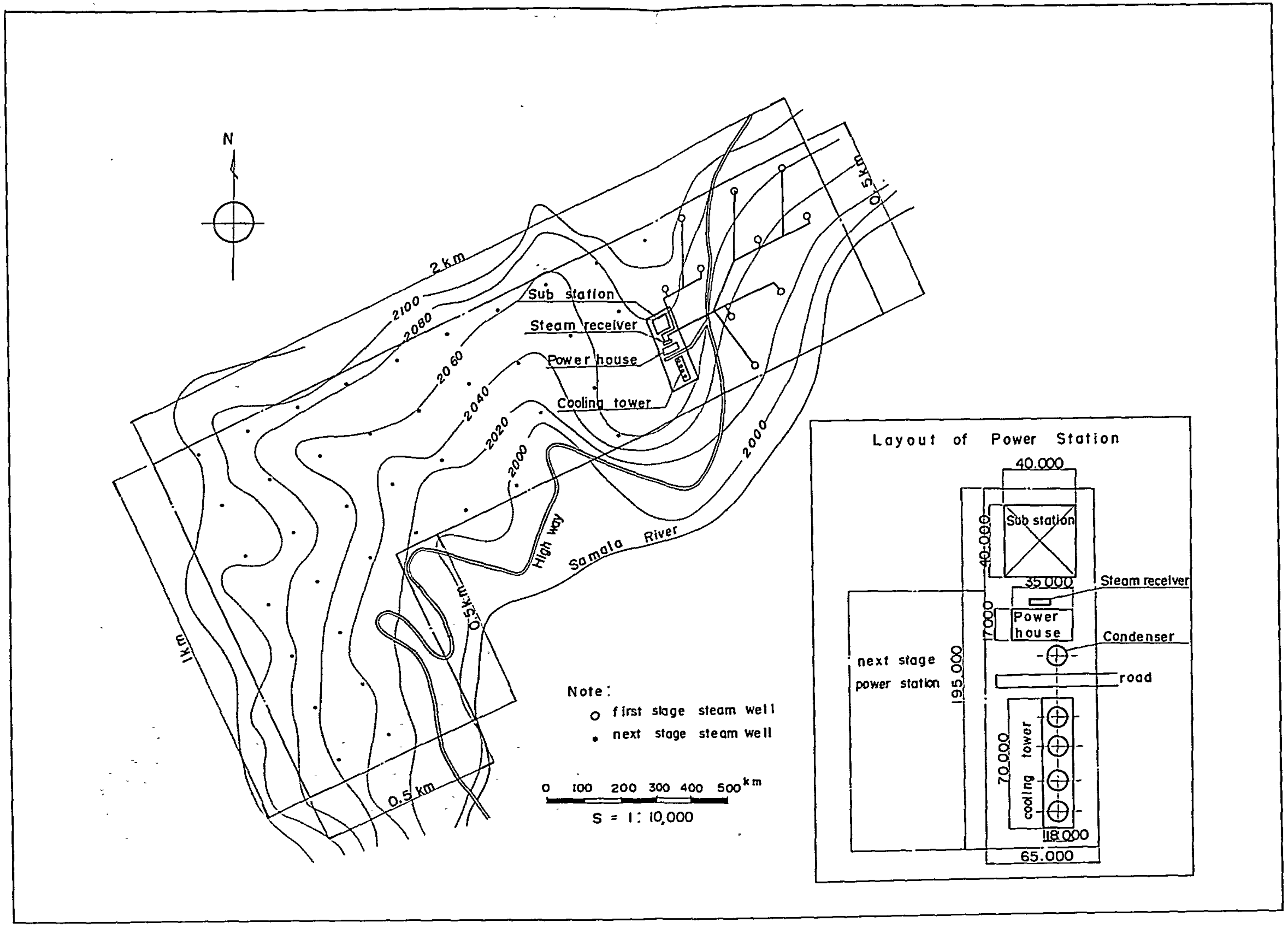
Table IX-2 Demand Forecast

Year	Annual KWH demand (10^6 KWH)	Loss (%)	Annual Generation	Seasonal Demand			
				Dry Season		Wet Season	
				Generation (10^6 KWH)	Generated Power MW	Generation (10^6 KWH)	Generated Power MW
1970	589	13	677	330	127	347	134
1971	662	13	761	371	143	390	151
1972	744	13	855	417	161	438	169
1973	836	13	961	469	181	492	190
1974	938	13	1078	526	203	552	213
1975	1052	13	1209	590	228	619	239
1976	1178	12	1339	653	252	686	265
1977	1318	12	1498	731	282	767	296
1978	1472	12	1673	816	315	857	331
1979	1642	12	1866	911	352	955	369
1980	1830	12	2080	1015	392	1065	412
1981	2035	12	2313	1129	436	1184	457
1982	2261	12	2569	1254	484	1315	508
1983	2507	12	2849	1390	537	1459	564
1984	2777	12	3156	1540	595	1616	624
1985	3070	12	3489	1703	658	1786	690
1986	3388	12	3850	1879	726	1971	762
1987	3734	12	4243	2071	800	2172	839
1988	4105	12	4665	2277	879	2388	923
1989	4506	12	5120	2499	965	2621	1013
1990	4937	12	5610	2738	1058	2872	1110

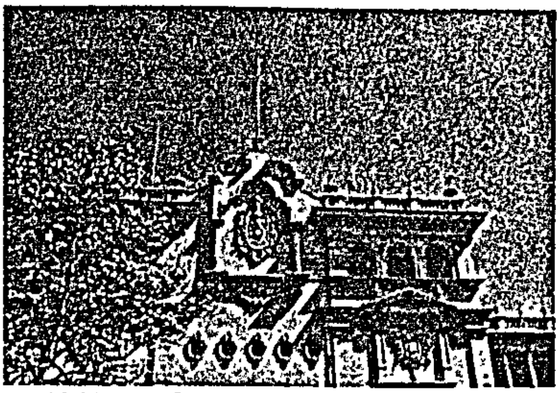
Table IX - 3 Electric Power Generating Facilities in Guatemala in 1976

Name of Power Station	Name of Company	Existing or Planned	Capacity of Facility (MW)	Generation 10^6 kW II		
				Dry season	Wet season	Total
Hydro						
Complejo Micheloya-Rio Hondo	INDE	Existing	10			
Santa Maria	INDE	Existing	6	27	40	67
Los Esclavos	INDE	Existing	6.5 x 2	15	52	67
Jurun Marinaia	INDE	Existing	20 x 3	90	106	196
Sub-total			89	132	198	330
Thermal						
La Laguna	EEG	Existing	3.5 x 2	–	–	200
Guacalate			11.5 x 2			
Escuintla	INDE	1972	33	–	–	240
		1975	50	–	–	400
		1976	50	–	–	400
Sub-total			163			1,240
Gas Turbine						
La Laguna	EEG	Established	12.5	–	–	30
Guacalate	INDE	Established	12.5 x 2	–	–	60
Sub-total			37.5			90
Diesel						
Castellana	EEG	Existing	1 x 5	–	–	5
La Laguna	EEG	Existing	1 x 4	–	–	4
Sub-total			9			9
Total			298.5			1,669

Fig. IX – I LOCATION OF ZUNIL GEOTHERNAL POWER STATION

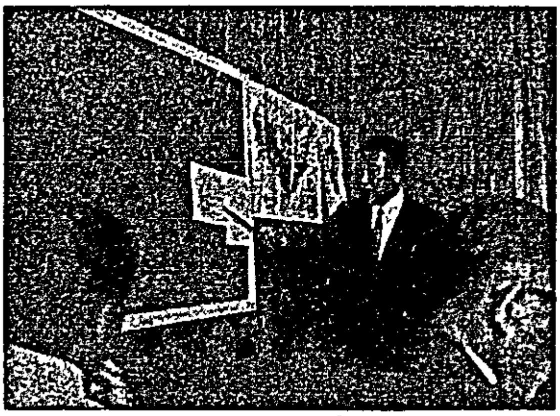


[Photo. I]



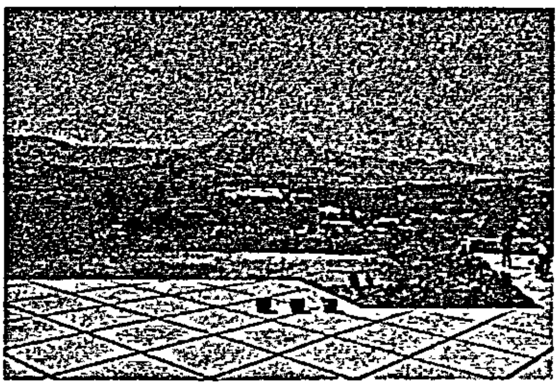
Building of the Guatemala Government

Relief Map

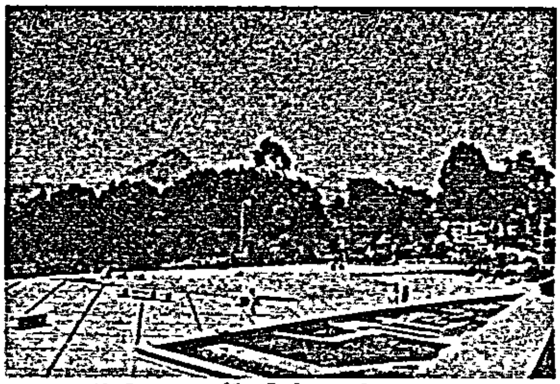


Survey Mission leader's speech on the report at INDE

Report meeting at INDE

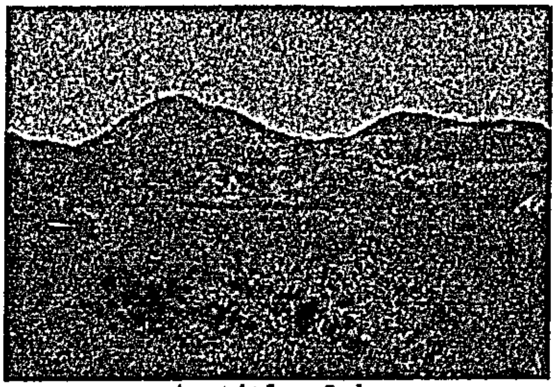


Pacaya Jolcano



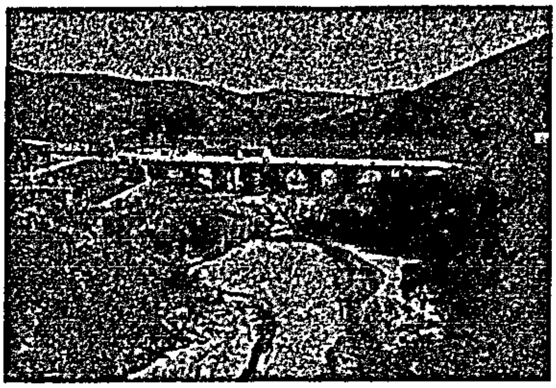
Agua Volcano (left) and Fuego Volcano

[Photo. II]

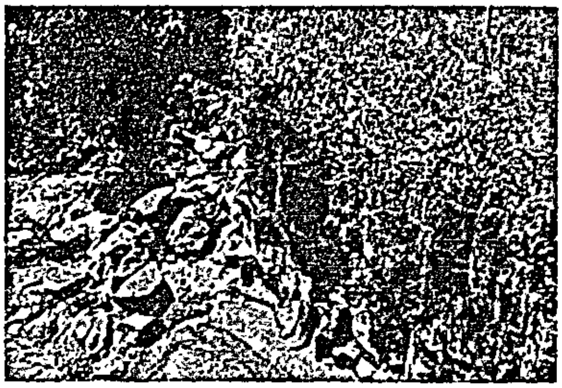


Amatitlan Lake

Amatitlan Lake and Agua Volcano



El Molino Dam

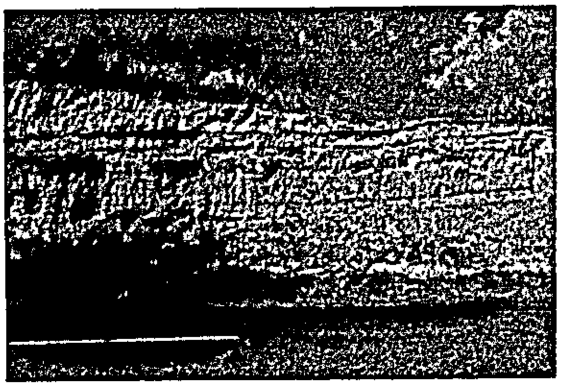


Dacitic welded tuff out copping
at the Molino Dam site

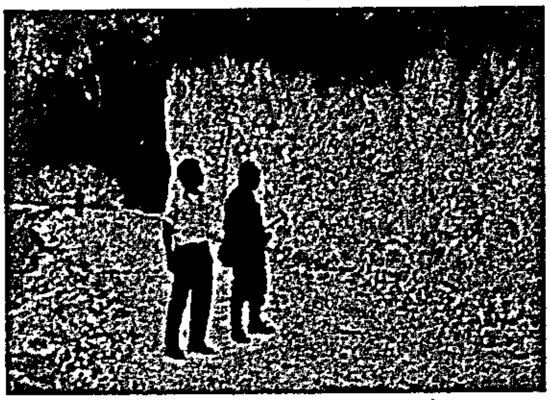
Caldera of Moyuta

[Photo. III]

Pyrocrastic fall deposits of north of Moyuta



Quaternary Lake deposit, north of Moyuta



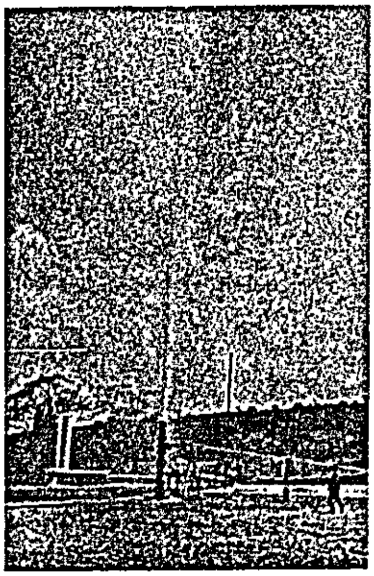
Thermal alterations near Ginea, Moyuta

Ginea Hotspring, Moyuta

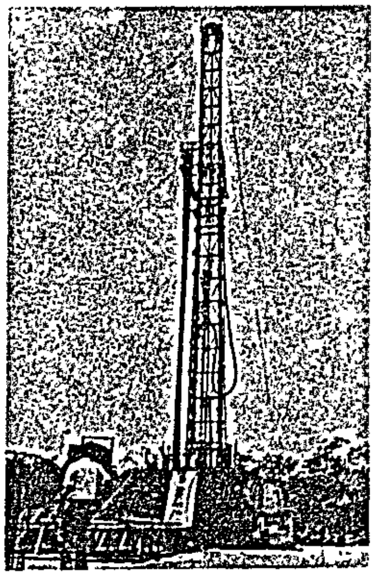
Alteration zone of Marukuchi, Moyuta

Geothermal area of Azulco, Moyuta

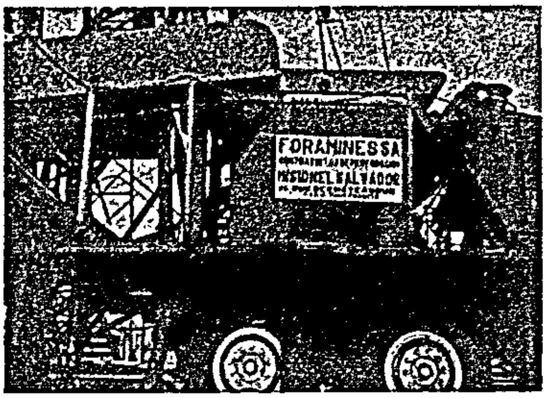
[Photo. IV]



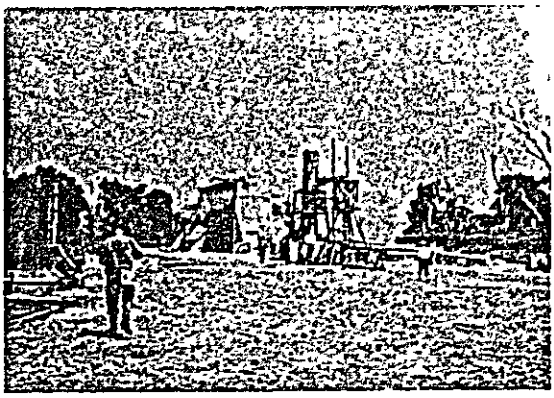
Spouting steam well,
Ahuachapan



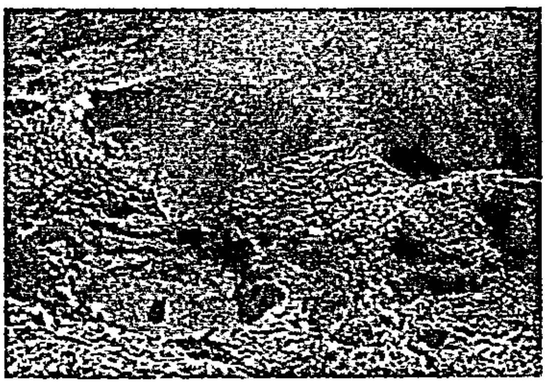
Well under drilling,
Ahuachapan



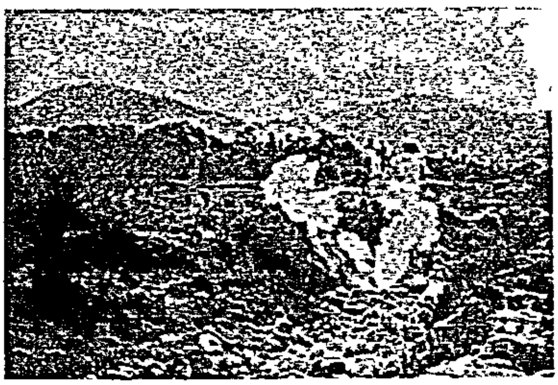
Boring ring, Ahuachan



Wellhead equipment, Ahuachapan



Mudpot spring, Ahuachapan



Fumarolic ground, Ahuachapan

[Photo. V]

Santa Maria Volcano

Canyon of Zunil geothermal area

Middle formation of Zunil Group

Middle formation of Zunil Group

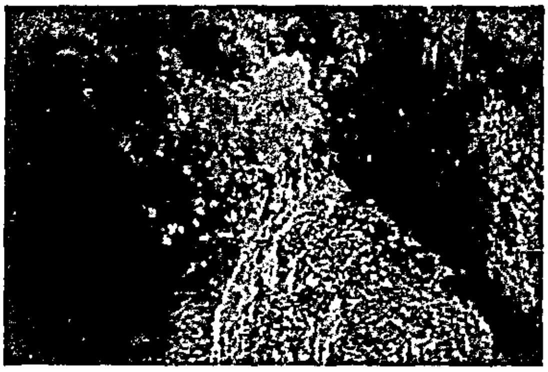
Columnar joint of pyroxene andesite lava, Middle formation of Zunil Group

Almolonga lava intruding into the Middle formation of Zunil Group

[Photo. VI]

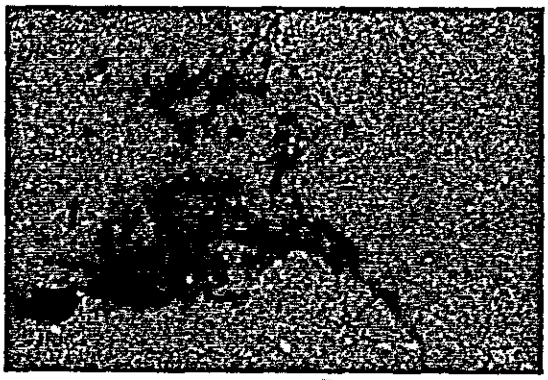
Zunil water-fall

Zunil water-fall and fault



Fumarole Grande, Zunil Geothermal Field

A distant view of Fumarolic Grande

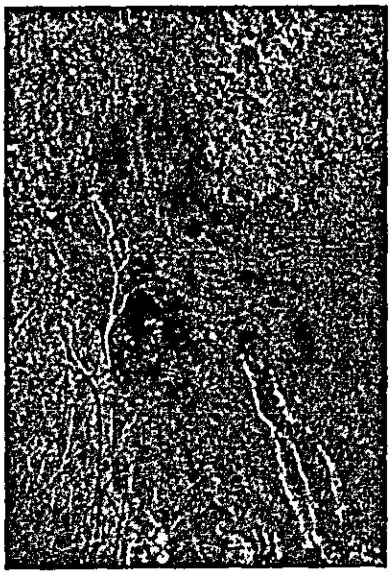


Pyroclastic flow deposit of Central formation

Planation surface (left down side) of Lower formation of Zunil Group, and Zanil lava (right)

[Photo. VII]

Fumarole Grande



Ditto

Utilization of geothermics

Sinter deposit

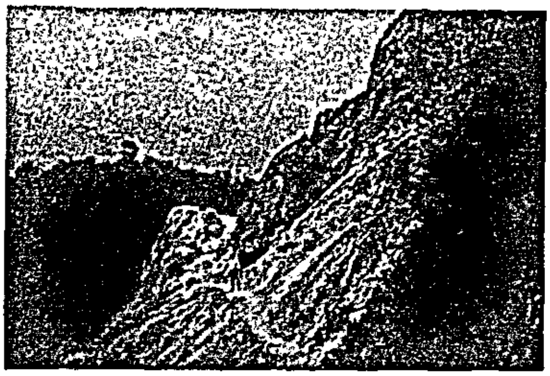
Canyon of Fumarole Grande

A distant view of Paxmux Fumarole, Zunil

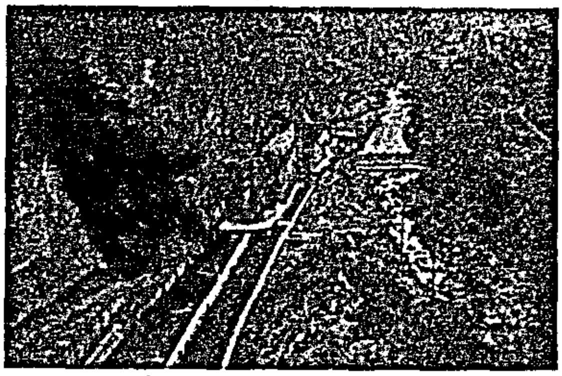
[Photo. VIII]

Hot Spring, Zunil

Hot Spring, Zunil



Alternation zone of Zunil water-fall



Waterway for the electric generation, down stream of Zunil. The left cliff is composed of Upper formation of Zunil Group.

Fumarole beside the road, northwest of Zunil

Balneario Aguas Amargas

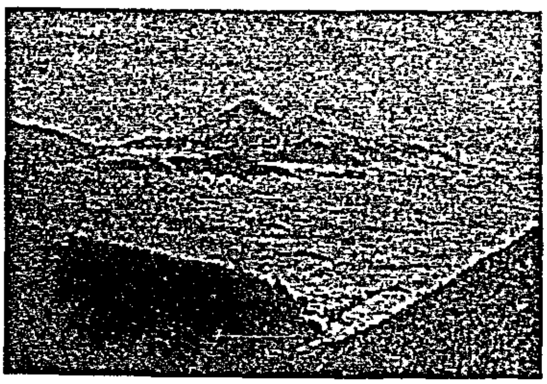
[Photo. IX]

Balneario Fuentes Georginas

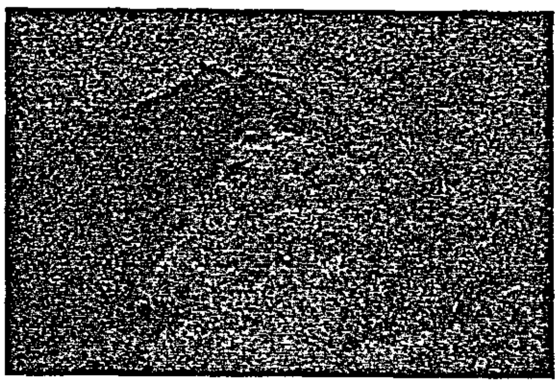
Asuncion Mita: Bicarbonat carbonate sodium chrorid type spring, temperature 71°C, iron hydrate, aluminium hydrate and calcium carbonate are deposited as a beautiful sinter like palette. Hotspring is seems to be spouted by carbonic acide gas.

Ixpaco Lake, containing sulphur pH 1.6, hotspring heated by geothermal steam flows out at the lake side.

Ixpaco: High temperature sodium spring (82°C), sinter of sodium and travertine is deposited on the rock.



Quezaltenango basin and Santa Maria Volcano



Volcan de Fuego and Volcan de Agua

[Photo. X]

Zunil Hot spring, Guatemala.

Ahuachapan geothermal area, El Salvador.

Guinea Fumarole, Moyuta geothermal area, Guatemala.

Azulco Fumarole, Moyutageo thermal area, Guatemala.