Japan International Cooperation Agency (JICA)

Instituto Nacional de Electrificacion,

The Republic of Guatemala

Amatitlan Geothermal Development Project

FINAL REPORT

Summary

December 2001

West Japan Engineering Consultants, Inc.

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1. OUTLINE OF THE PROJECT

1.1 BACKGROUND

In September 1997, the Guatemalan Government requested to the Japanese Government, through the Japanese Embassy in Guatemala, technical assistance to define the extension of the Amatitlan geothermal field. This assistance would also be to provide Instituto Nacional de Electrificacion (INDE) with the advice on the most appropriate operative scheme of a geothermal power plant to exploit the geothermal resource in this field.

In May 1998, The Japan International Co-operation Agency (JICA) and INDE entered an agreement to fulfil the request and the present project entitled "**Amatitlan Geothermal Development Project**" was officially admitted. The studies commenced on September 1998.

1.2 OBJECTIVES OF THE STUDY

The objective of the study is to determine the extension of the Amatitlan geothermal field and to assess, from the technical, economical and financial points of views, the viability of exploiting, in a sustainable manner, the geothermal resources for electricity production. In addition, as an important component of the present Technical Co-operation, the objective was set to carry out "on the job" technical training and transfer of technology to INDE's personnel.

1.3 OUTLINE OF THE STUDY AND WORK CONTENT OF EACH STAGE

1.3.1 OUTLINE OF THE STUDY

The basic plan for the project was agreed on May 18, 1998 between The Ministry of Mines and Energy, Instituto Nacional de Electrificacion and the Japan International Cooperation Agency. The detailed structure and contents were defined in the Terms of Reference published on July 17, 1998.

The activities for the project, which included the drilling of two exploratory wells, were originally accommodated into three stages, Each of these stages were scheduled to be carried out during the Japanese fiscal years 1998, 1999 and 2000, respectively. However during the execution of Stage-1, the time line for the project was modified to allow the drilling of one well during the Fiscal Year 1999 and to postpone the drilling of the second well to the Fiscal Year 2000.

i) STAGE-1: Preliminary Survey Stage (Fiscal Year 1998)

- i-1 Preparation in Japan (Inception Report & Preparation of Field Logistic)
- i-2 First Term of Services in Guatemala (Focus Mission & Geoscientific Field Survey)
- i-3 First Term of Services in Japan (Data Processing Integration & Preparation for Drilling)
- i-4 Second Term of Services in Guatemala (Progress Report & Presentation of Results)

ii) STAGE-2: Detailed Survey Stage (Fiscal Year 1999)

- ii-1 Second Term of Services in Japan (Bid Document, Draft Contract)
- ii-2 Third Term of Services in Guatemala (Bidding, Drilling of one vertical

well, Approval of total depth, Well completion testing, Well Geology).
ii-3 Third Term of Services in Japan: Progress Report

iii) STAGE-3: Detailed Survey Stage (Fiscal Year 2000)
iii-1 Fourth Term of Services in Guatemala (Bidding for drilling works, Flow Testing of well No.1 and Technical Seminar in Guatemala, Drilling of No.2 well and its completion testing, Flow Testing of wells No.1 and No.2, Well Geology of well No. 2, Environmental Studies)
iii-2 Fourth Term of Services in Japan (Data Analysis, Resource Assessment, Study for Optimum size and basic layout of power plant, Interim Report)
iii-3 Fifth Term of Services in Guatemala (Presentation of Interim Report, Technical Seminar in Guatemala, Data Collection for the Feasibility Study)

iv) STAGE-4: Feasibility Study Stage (Fiscal Year 2000)

iii-2 Fifth Term of Services in Japan (Exploitation Scheme, Feasibility Study & Draft Final Report)
iii-3 Sixth Term of Services in Guatemala (Presentation of the Draft Final Report)
iii-4 Sixth Term of Services in Japan (Final Report)

1.3.2 Description of the Services for the 2001 Fiscal Year (Feasibility Study)

Refer to Table 1-1-1.

1. Fifth Term of Services in Japan:

*Data analysis for acquired data in Guatemala and forecasting of the reservoir response

*Layout of the generation facilities

*Construction plan of power plant

*Calculation for construction cost

*Environmental impact assessment

*Economical and financial evaluation

*Integration, consideration and recommendation

*Preparation for the draft of the Final Report

2. Sixth Term of Services in Guatemala

JICA team carried out the explanation and discussion on the draft of the Final Report and collected the comments from the Guatemalan side.

*Explanation and discussion on the draft of the Final Report

3. Sixth Term of Services in Japan

Following the comments from Guatemala side, the draft report was revised at the necessary part and the Final Report was prepared for.

*Preparation for the Final Report

1.4 SURVEY TEAM

In accordance with the scope of work, the following organizations were in charge of the study.

Japan	:	Japan International Cooperation Agency (JICA)
		West Japan Engineering Consultants, INC. (JICA Team)
Guatemala	:	Ministry of Energy and Mines
		National Institute of Electrification (INDE)

The JICA Team, and INDE were organized into the following staff to carry out the study.

JICA Team	
Project Manager	Toshio FUJINO
Reservoir Engineer	Enrique LIMA
Reservoir Engineer	Tetsuya YAHARA
Electrical Engineer	Kenji SAKEMURA
Mechanical Engineer	Takeshi YAMAMOTO
Environmental Engineer	Kazuo HIROWATARI
Economist	Kenji FUJII
INDE	
General Manager	Eng. Julio Palma Ayala
Geologist	Eng. Victor Ortiz Corzo
Geochemist	Eng. Alfredo Roldan Manzo
Geophysicist	Dr. Juan Pablo Ligorria
Civil Engineer	Eng. Juan Torres Bernabes
Reservoir Engineer	Eng. Haroldo Cuevas

1.5 ACKNOWLEDGEMENTS

JICA team wishes to express their sincere appreciation for the support and assistance given by Ministry of Energy and Mines, INDE and Japanese Embassy and JICA office in Guatemala.

Table 1-1-1 Activities Schedule
作業実施工程

Activities \ Fiscal year / Month	2001 Fiscal Year 7	8	9	10	11	12	1
3. Feasibility Study Stage							
(1) 5th Term of Services in Japan							
①Analysing of the collected data and forecasting of reservoir response	July. 2 July. 16						
②Conceptual Design of Power Plant	July. 2 July. 16						
③Construction Plan of Power Plan	July. 2 July. 16						
④Cost Estimation	July. 2 July. 16						
⑤Environment Impact Assessment		Aug. 1 Aug. 15					
⑥Economical and Financial Evaluation		Aug. 1 Aug. 30					
⑦Evaluation and Integration			Sep. 3 Sep. 17				
⑧Preparation for the Draft of the Final Report			Sep. 16 Sep. 30				
(2) 6th Term of Services in Guatemala				Oct. 21 Oct. 29 Draft			
①Explanation and Discussion about the Content of the Draft Report				(Work in Guatemala)			
(3) 6th Term of Services in Japan						F/R	
①Preparation of the Final Report							

Legend : ■ Work in Guatemala □ Work in Japan △—△ Report

2 SUMMARY OF THE SURVEYS DONE IN PREVIOUS YEARS

2.1 Update of the Power Sector

2.1.1 Overview of the electric sector of Guatemala

2.1.2 The Generation System

2.1.3 The Transmission System

2.1.4 The Distribution System

2.1.5 Demand Forecast for the SNI

2.1.6 Update of Economy and Political Aspects

2.1.7 Political Situations

2.1.8 Actions to improve the Coverage and to secure the Electricity Supply

2.1.9 Alternatives for Power Generation in Guatemala

2.1.10 Conclusion

2. SUMMARY OF THE SURVEYS DONE IN PREVIOUS YEARS

2.1 THE AMATITLAN PROJECT WITHIN THE ELECTRIC SECTOR OF GUATEMALA

The success of a geothermal development for electricity production in Amatitlan will depend not only on the quantity and quality of the geothermal resource but also it will depend factors, such as those mentioned below, that will influence the economy and operation of the power facilities.

- The structure of the Guatemalan electric sector and its trend of evolution,
- Present and future supply and demand
- Policies devised by the government to allow adequate response (private and public) to the power demand
- Participation of alternatives for a balanced energy mix in satisfying the power demand.

2.1.1 Overview of the electric sector of Guatemala

1. The General Electricity Law

The government of Guatemala enacted three decrees upon which the Electric Sector of the country has been reformed. Reforms started in November 15, 1996 when the General Electricity Law (here after referred as to "the Law"), Decree No. 93-96 was enacted to provide the general frame to the present structure of the sector. To provide a means to enforce the Law, the Government enacted the Regulatory Decree on April 2^{nd}, 1997 (Decree No. 256-97). These two decrees established the rules for private and public entities to participate and do business in the generation, transmission and distribution of electricity in the Republic of Guatemala. At the same time, these two decrees established rules to enhance the service and to protect the costumers. On June 1^{st}, 1998 the Regulatory Laws for the Wholesale market were enacted to complete the rules and framework under which the Guatemalan Electric Sector is erected.

The Law created a Wholesale Market to integrate all these activities under two basic precepts:

- Freedom to build and operate power facilities and
- Fair competition to allocate generating energy in the market upon freedom

to set the price of generated electricity.

The Ministry of Energy and Mines of Guatemala is held responsible for the planning and coordination of policies for the electric sector. To watch over and exert regulatory activities, the Law created the National Commission of Electric Energy (Comisión Nacional de Energía Eléctrica, CNEE). To do the dispatching and general management of the Power sector, the Law and its regulations created an Administrator of the Wholesale Electric Market (Administrador del Mercado Mayorista, AMM). This relationship is depicted in Figure 2-1-1-a..

2. The National Commission of Electric Energy (CNEE)

- The mission of the National Commission of Electric Energy is to create the environment for the free and fair participation of any entity (individual or legal) in the generation, transmission, distribution and commercialization of electric energy in Guatemala.

3. Wholesale Market Administrator (AMM)

Clause 44 of the Law establishes the creation of the Wholesale Market Administrator as a non-lucrative private entity responsible of the:

- Coordination of the dispatching of all power plants connected to the National Interconnected System (SNI), coordination of the international exports and imports and coordination of the national transmission system to ensure a supply of electricity in Guatemala of the minimum cost,
- To ensure free contracting between the different agents of the electric sector for the trading of energy and to ensure non-discriminatory transmission and distribution of electricity.
- To establish, contract schemes for the regulated market for the short-term supply of energy and capacity.
- To secure and guarantee the supply of energy in the Republic of Guatemala.

The AMM is a private entity conformed by representatives of the seven agents of the Guatemalan electric sector (government and private);

- Electricity generation (those with capacity larger than 10 MW),
- Electricity transmission (those showing contracted Capacity > 10 MW),

- Electricity distribution (those showing more than 20,000 customers),
- Brokers ("Comercializadoras in Spanish" those with contracted capacity > 10 MW),
- Large consumers (> 100kW),
- Importers (trading more than 10 MW),
- Exporters (trading more than 10 MW).

4. Operation of the Wholesale Market

One peculiar characteristic of the Guatemalan electricity market is a separated market of capacity and energy. This is because upon the Law, the three main activities of the electricity business; generation, transmission and distribution were separated and because to be accredited as a distributor agent or as a broker agent (including importers or exporters), the Law imposes on them the necessity of securing, through contracts, a minimum of 10 MW in capacity. Therefore, generating companies enter contracts with distributors and/or brokers to provide them with the capacity they need to be accredited by the Law and separately these generation agents can sell their energy through contracts with other agents or customers (refer to Fig. 2-1-1-b).

Capacity is sold in a range between 10 to 12 \$/MW-month for thermal generation and in a range between 15 and 18 \$/kW-month for hydro power. The prices are determined so as to allow amortization of capital in 8 years at a discount rate of 10% and a grace period of 1 year for thermal plants and 3 years for hydro plants. There is not any specific provision for geothermal energy but it is said that provisions for the Hydro power plants would apply for all other renewables.

Distribution companies and brokers purchase energy (\$/kWh) from the wholesale market through private Power Purchase Agreements (PPA) with other agents or at the spot market (also called opportunity market).

It is in the spot market where generators compete with their price of energy. The generators present every week to the AMM their intended total supply and the expected variable costs for the energy the generators intend to put in the spot market. With this information, the AMM makes the weekly dispatch program.

For executing the program the AMM dispatches the energy in contracts between agents (where prices are already agreed). To supply the rest of demand the generation prices (variable costs of generators) are revised every hour and the power plants are dispatched from the cheapest to the most expensive in that hour. Figure 2-1-2 schematically depicts the form of dispatching plants. Table 2-1-1 shows the average hourly energy price of the spot market at "Guatemala Sur" substation for the month of May, 2001.

Energy is allocated to either a Regulated or to a Non-Regulated Market.

a. Non-Regulated Market

Generators can negotiate their available capacity and energy with large consumers (those consuming above 100kW). The contracts are private and the government has no inherence in their terms. Prices of energy can be as low as US$ 0.020/kWh

b. The regulated Market

- This market is for consumers of less than 100 kW, municipalities and government. The CNEE oversees and control the electric tariff (Selling Price per kWh to customers). The electric tariff is set in such way as to pass thru the cost of fuel to consumers.

The government through INDE subsidized the regulated market (the so called Social Tariff). The price without subsidy to the consumers was 1.19 Q/ kWh (@7.85 Q/$ this price was 0.15$/kWh), while the subsidized prices were 0.78 Q/kWh (0.094 $/kWh at the same exchange rate).

5. Trading Electricity and Complementary Services

Trading electric energy and the necessary complementary services for the full operation of the Wholesale market has created three different markets.

- The Spot (Opportunity) Market
- The Market of Contracts of Limited Terms
- The Deviations Market

2.1.2 The generation System

The generation system is conformed of all public and private generation facilities. INDE represents the public sector. The private sector is represented by companies with ECA's entered with INDE, companies with PPA's entered with other agents and companies operating as merchant plants. Fig. 2-1-2 shows the inter-relation between the generation system and the other agents of the electric sector in Guatemala. Table 2-1-2 shows a detail of the composition of the generation system

2.1.3 The Transmission System

The transmission system is own by the State of Guatemala. INDE holds the Transmission and Control of Electric Energy (Empresa de Transporte y Control de Energía Eléctrica, ETCEE), which is in charge of the transmission of electricity in Guatemala. EEGSA operates its own transmission system in the central part of Guatemala (Fig. 2-1-3).

2.1.4 The distribution System

The distribution system changed when EEGSA was privatized and separated into a distribution company and a generation company. The generation facilities of the old EEGSA were sold to Constellation of the USA and the distribution assets to Iberdrola of Spain. The new EEGSA serves the capital city and the surrounding areas. The distribution assets and areas of service of INDE were sold to Union Fenosa of Spain. The service area of Union Fenosa is divided into a western and eastern areas, refer to Fig. 2-1-4.

2.1.5 Demand forecast for the SNI

The growth in the install capacity in the Guatemalan electric sector has been one of the highest in Central America. The conditions of the market and its characteristics have been incentive for the private sector. Recently a slow down have been noticed, due to uncertainties in the political and economical systems and the variation of fossil fuels. Nevertheless, in global terms, the growth has been positive. Figure 2-1-5 presents the growth rate in the install capacity until year 2000.

2.1.6 Up date of economy and political aspects.

Alfonso Portillo of the Frente Republicano Guatemalteco (FRG) political party was inaugurated as President of Guatemala in mid-January 2000. He proposed a budget that would use some tax increases, in addition to other measures, to reduce the fiscal deficit. The budget that was eventually approved uses further spending cuts and earnings from privatizations to reduce the country's fiscal deficit. Some economic indicators have improved in recent months, with interest rates lower and less volatile, inflation is under control, and the country's currency, the quetzal is stronger..

2.1.7 Political situation

The present administration is the fifth civil administration in row. This continuity allows the private investor to feel relaxed in the respect of law and private property. This circumstance and the end of the cold war liberated capitals that flown to the developing world.

The approval of laws like the General Law of Electricity and the vision of responsible administrators of the past opened the door to the inflow of capitals to build new infrastructure. From 1991 this inflow of capital is evident in the construction of buildings, supermarkets, new roads, etc.. The continuation of this growth will drive even higher the need of additional electrical infrastructure

2.1.8 Actions to improve the coverage and to secure the electricity supply

1. Rural Electrification

   The aim of the government of Guatemala is to increment the electrification coverage to a 90% by the year 2004 and to a 96% by the year 2006.

2. Utilization of Renewable Resources

   The recent growth in the installed capacity has been mainly through private investments in fossil fuels power facilities. More than the 50% of the demand is satisfied by power facilities burning fossil fuels. The fossil fuels alternatives, although comparatively cheap and of rapid deployment, represents an unbalanced energy mix. Guatemala depends excessively in imported fuels. To sustain the forecasted economy growth, Guatemala must reduce this dependence and promote the utilization of domestic resources.

   The ministry of Energy and Mines is promoting a decree to promote fiscal, financial and administrative incentives. To the date of writing this report, this decree has been sent for discussion to the Congress of the Republic.

   The state of Guatemala is sovereign owner of all natural resources. However, to assess and develop these natural resources the Electricity Law allows temporary concessions. Concessions can be granted by the Ministry of Energy and Mines, to private and/or public enterprises. In case of geothermal, a maximum of 10,000 km^2 can be given in concession for field assessments and a maximum of 100 km^2 for exploitation. In the case the private enterprise accepts to limit the exploitation to 5 MW no special concession is required. The Electricity Law stipulates a maximum of one year for the private or public enterprise to assess the geothermal potential.

2.1.9 Alternatives for power generation in Guatemala

1. Geothermal alternatives

Guatemala is blessed with geothermal resources, from North to South, the San Marcos, Zunil-I, Zunil-II, Totonicapan, Atitlan, Michatoya Valley, Palencia, Tecuamburro, Moyuta and Laguna Retana are geothermal areas that in addition to Amatitlan from where Guatemala can draw much of the energy the country needs. All these areas are related to active volcanism and strong tectonic fracturing. Depending on the success of efforts to enact the Fiscal Incentives Law, geothermal developments of from 20 to 50 MW can be competitive and can fill the gap in the future power supply.

2. Non-geothermal alternatives

Several private investors have pursued in the development of small to medium hydroelectric resources. However this natural resource is highly dependent on the hydrological cycle and thus turns the utilization factor very low.

Natural gas represents a fast track competing alternative for geothermal developments in Guatemala. Until recently there was a plan to pipe natural gas from Mexico. However, the political situation and the economy in Mexico has delayed investments and now Mexico is a net importer of natural gas from the USA. Seems that the alternative of piping gas from Mexico will not represent a serious competitor for geothermal developments in Guatemala.

2.1.10 Concluding remarks.

1) The changes in the electric sector of Guatemala have been addressed to promote demonopolization and a fair participation of the private sector

2) Civil institutions and governments prevail. Though democracy is still young in general terms there is confidence in the political situation.

3) There is experience and confidence in Guatemala to handle private

participation not only in the power sector but also in other sectors of the society. The confidence is reflected in the considerable investments done to date.

4) The Guatemalan State will maintain presence in the electric sector through the transmission and the generation subsidiaries of INDE Holding until the decision of selling these companies to the private sector is made and executed.

5) The determination of the electric sector authorities to incorporate the rural areas to the grid might propel the increment of the demand to the levels forecasted for the High Demand Scenario.

6) According to the experience of the Guatemalan Wholesale Market, the price paid for energy (from US$0.02 to US$0.10 per KWh) permits to carry out investments with internal rate of return attractive at international level.

7) For small capacity plants, less then 50 MW using renewables resources such as geothermal, these variable pricing might hinder their competitive participation in the Wholesale market, but the enact of the Fiscal Incentive Law will make the resources competitive and attractive for investments.

8) From the alternatives to fill the gap in the energy supply with renewable resources, Geothermal is the best

9) The Laguna power plant was retired on August, 2001. Therefore a geothermal development in Amatitlan (Laguna Calderas) might represent a keen interest of Constellation to purchase capacity and or energy for substitution.

10) Unión Fenosa of Spain acquire a 240 MW capacity agreement from INDE to expire on December 2003. This distributor might be interested in purchasing capacity as well as energy from an eventual development at Amatitlan.

11) With whichever scenario (low, medium or high) to be present in the future, 20 MW or even 50 MW geothermal in Amatitlán connected to the grid will be easily absorbed by the system as base load.

Fig.2-1-1(a) Structure of the Guatemalan Electric Sector
グァテマラ電力産業の組織

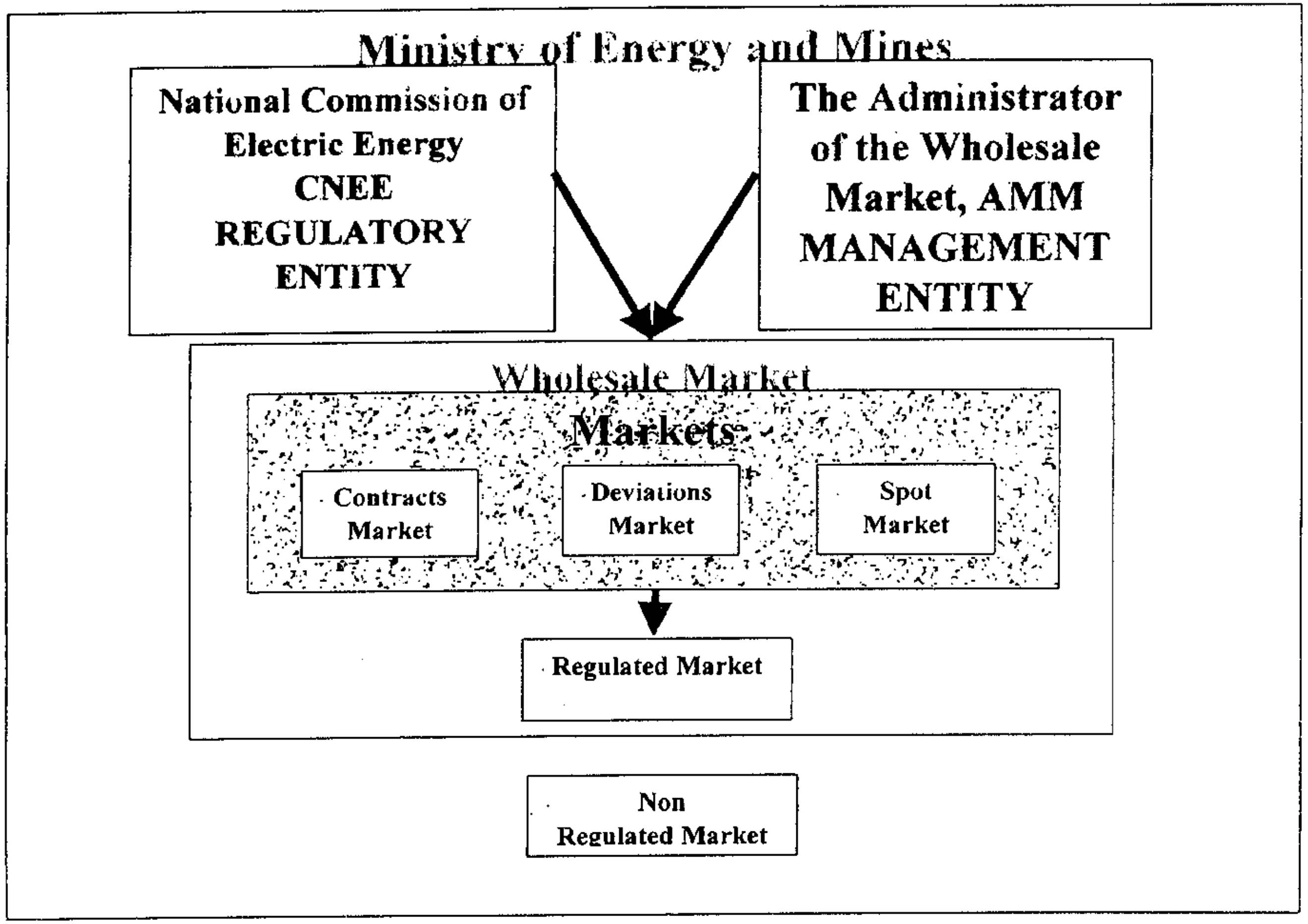


Fig. 2-1-1(b) Markets of the Guatemalan Power Sector
グァテマラ電力産業の市場構造

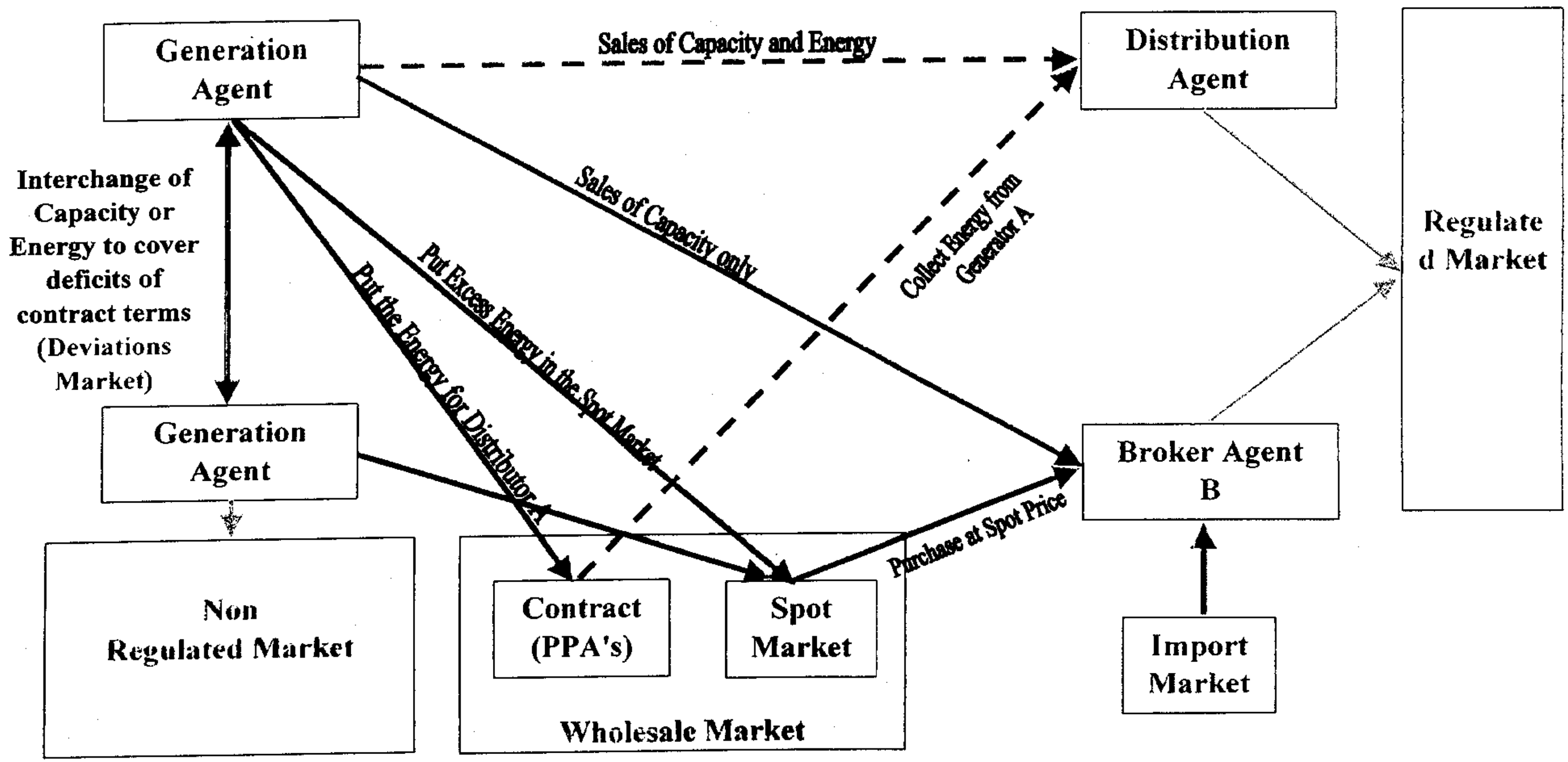


Fig. 2-1-2 Daily piling of energy costs
エネルギーコストの日変化

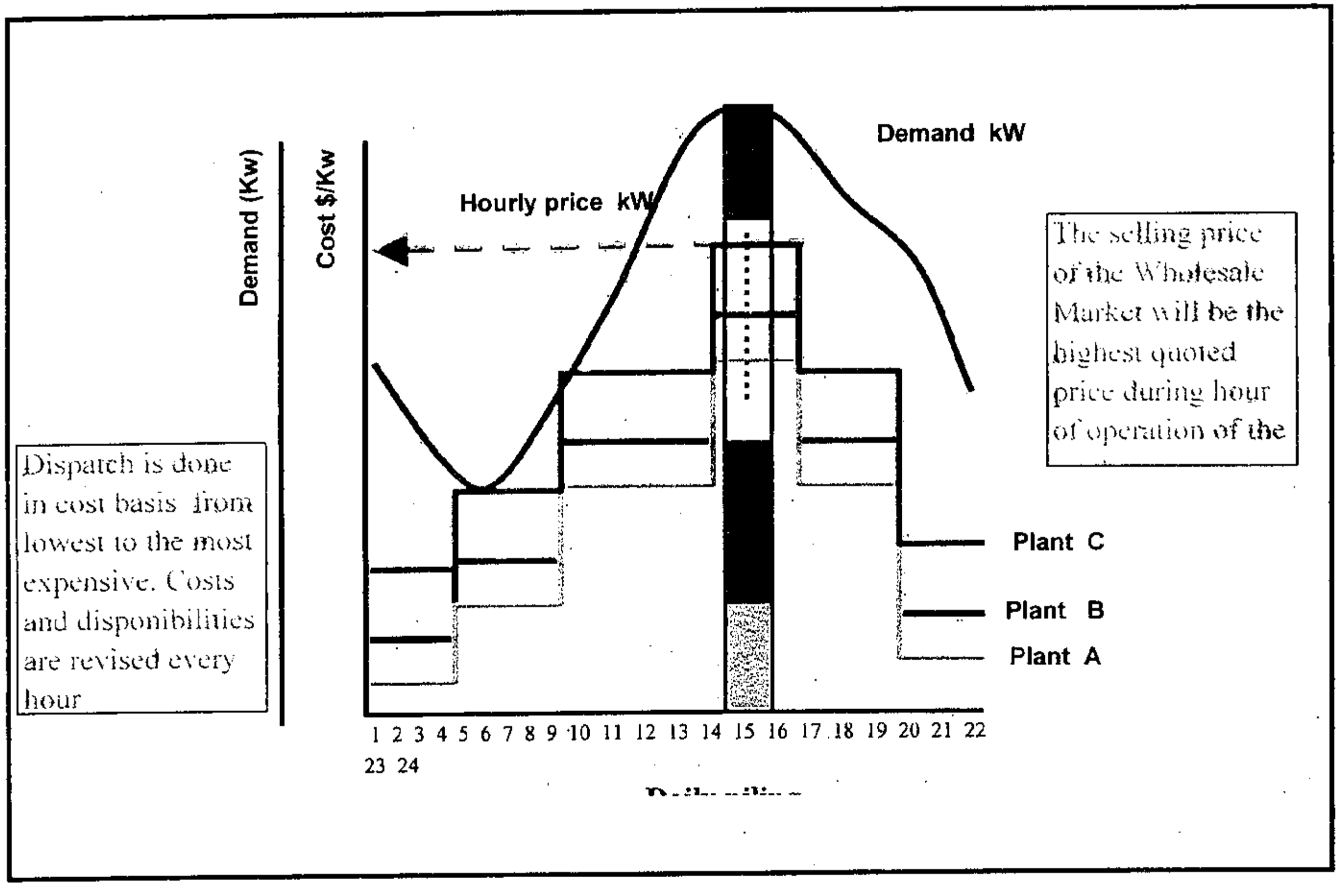


Fig. 2-1- 3 Structure of the Electricity Supply in Guatemala
グァテマラ国内の電力供給システム

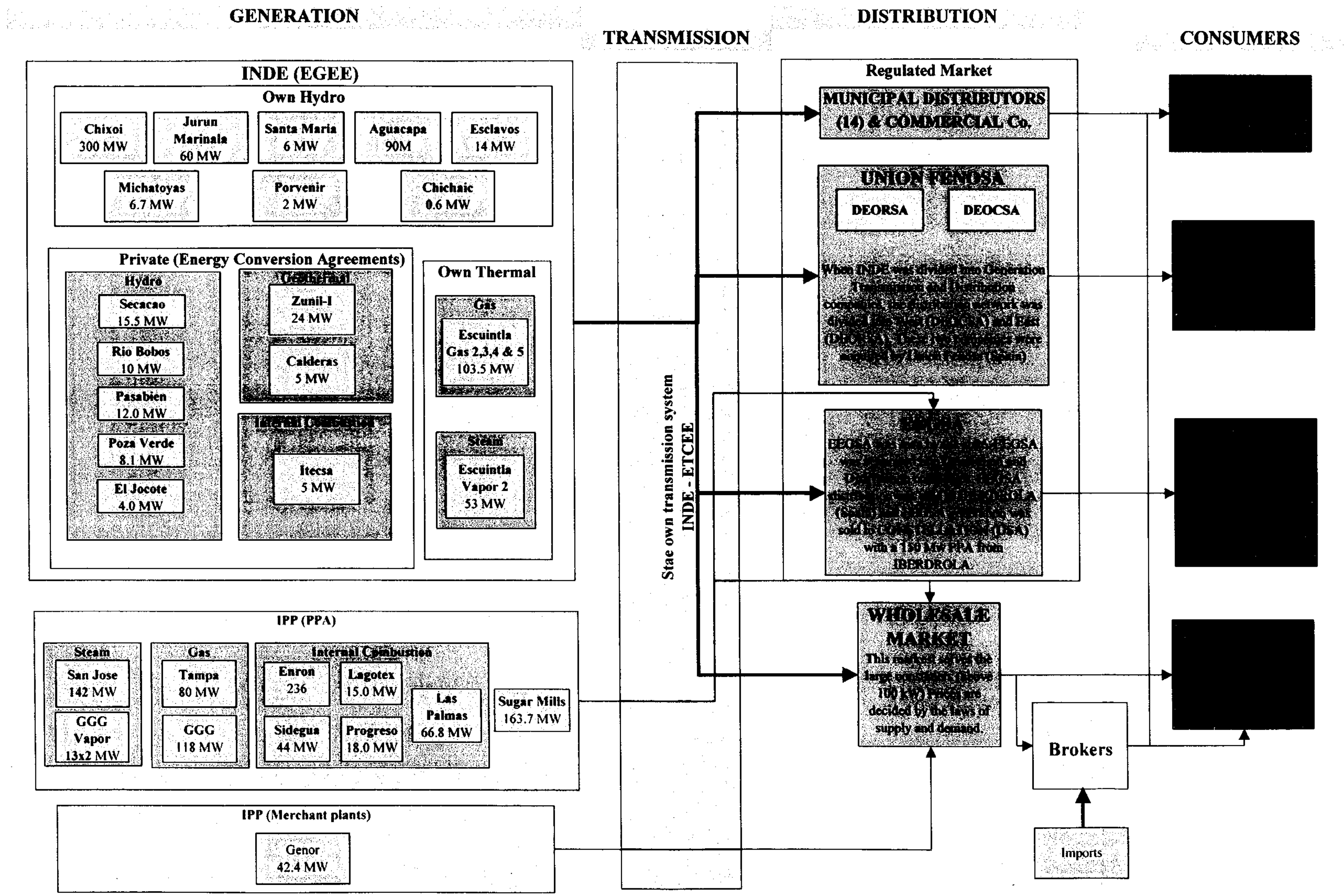


Fig. 2-1-3 Structure of the Electricity Supply in Guatemala
グァテマラ国内の電力供給システム

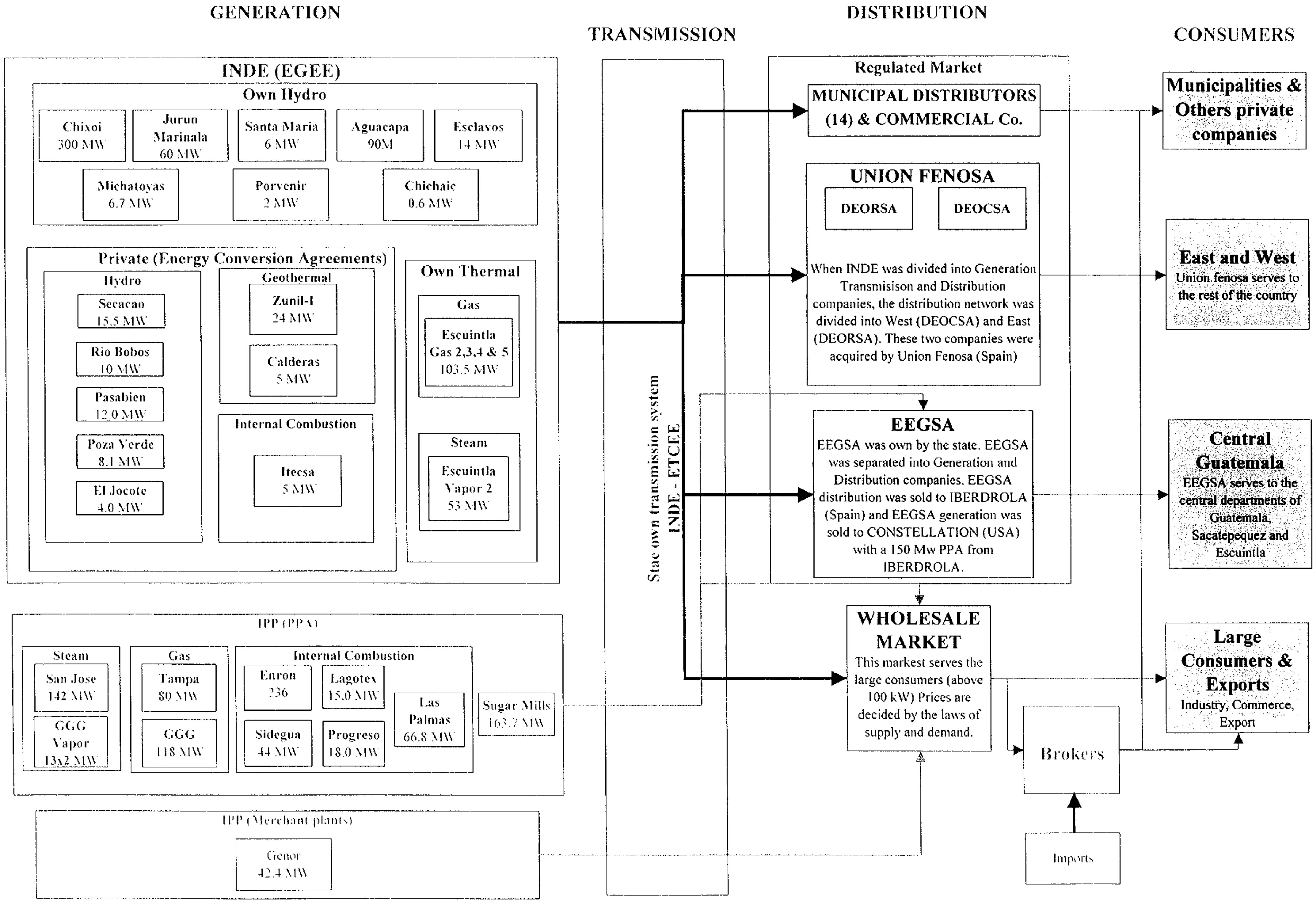
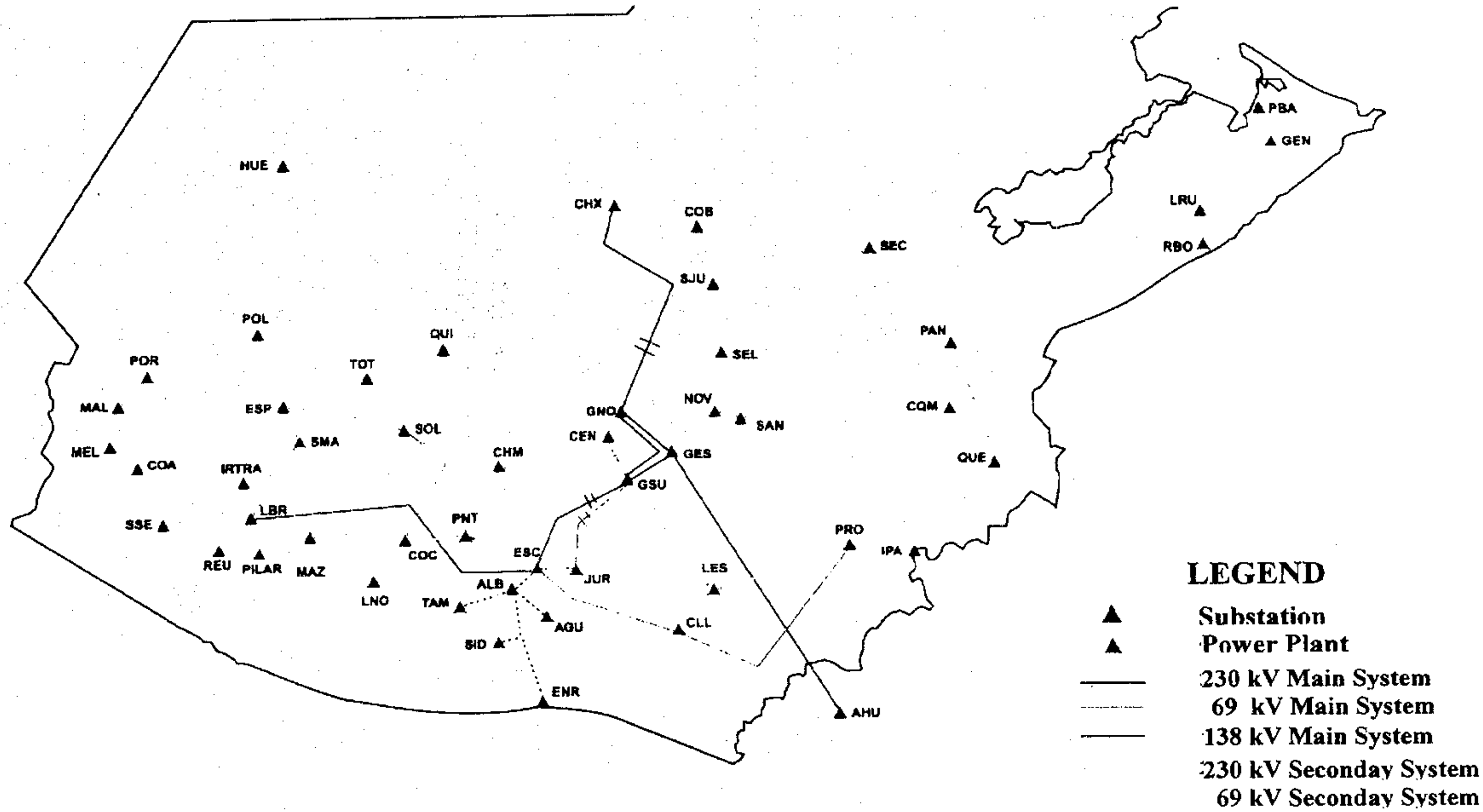


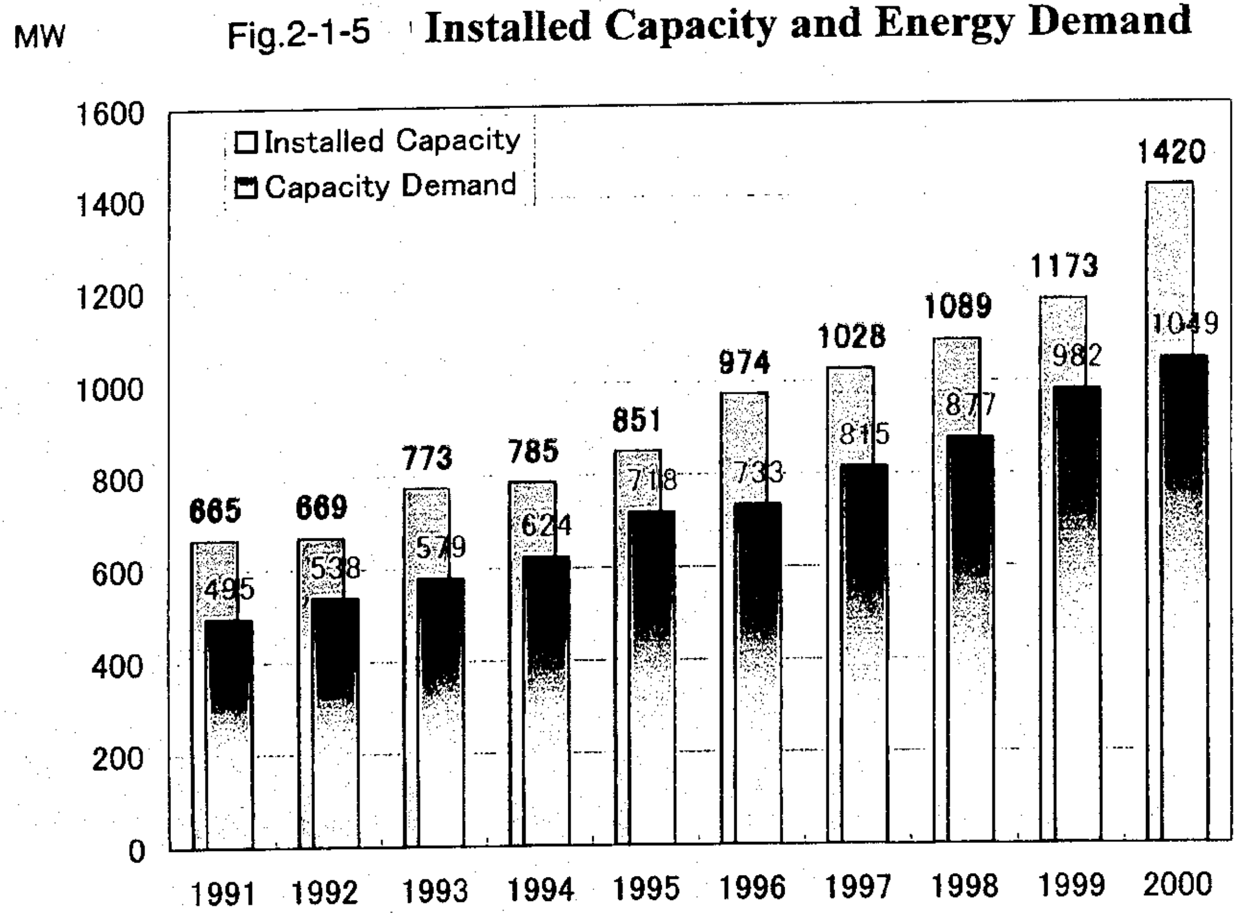
Fig.2-1-4 **The transmission System of Guatemala**
グァテマラ国内の送電システム



Source: MEM

設備容量と電力需要の推移

Fig.2-1-5 Installed Capacity and Energy Demand



2001年5月，Guatemala Sur給電所での時間別電力スポット価格

Table2-1-1 Spot Price of Energy at the Reference Node (GUATEMALA SUR 230 KV) in US$ / MWh, Period from May 01 to May 31, 2001

HORA \ DIA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Hour - Monthly Average	Max	Min
00:00-01:00	34.40	19.54	34.40	28.78	19.54	30.72	30.72	34.82	34.82	34.82	40.76	37.51	34.89	34.89	34.89	34.89	40.76	40.07	35.84	41.28	34.96	40.86	48.44	41.28	34.96	36.50	35.27	35.27	35.27	35.27	35.27	35.53	40.76	19.54
01:00-02:00	19.54	19.54	19.54	19.54	19.36	30.72	30.72	34.82	34.82	34.82	34.82	34.82	34.89	34.89	34.89	34.89	34.89	34.89	34.89	34.96	34.96	40.86	34.96	34.96	34.96	34.96	35.27	35.27	35.27	35.27	35.27	32.39	40.86	19.36
02:00-03:00	19.54	19.54	19.54	19.54	19.36	30.72	30.72	34.82	34.82	34.82	34.82	34.82	34.89	34.89	34.89	34.89	34.89	34.89	34.89	34.96	34.96	34.96	34.96	34.96	34.96	34.96	35.27	35.27	35.27	35.27	35.27	32.20	35.27	19.36
03:00-04:00	19.54	19.54	19.54	19.54	19.36	30.72	30.72	34.82	34.82	34.82	34.82	34.82	34.89	34.89	34.89	34.89	34.89	41.36	34.89	34.96	34.96	34.96	34.96	34.96	34.96	34.96	35.27	35.27	35.27	35.27	35.27	32.43	42.36	19.36
04:00-05:00	19.54	19.54	34.40	28.78	28.78	30.72	30.72	34.82	34.82	49.25	34.82	37.51	34.89	34.89	49.22	34.89	41.36	49.76	37.61	34.96	34.96	34.96	37.61	34.96	34.96	40.86	35.27	35.27	35.27	35.27	35.27	35.34	49.76	19.54
05:00-06:00	19.54	19.54	34.40	34.40	34.40	30.72	34.82	49.25	49.25	49.25	49.25	37.51	34.89	42.36	49.76	49.76	49.76	56.37	49.76	34.96	52.48	48.44	52.48	41.28	37.61	40.88	35.27	35.90	35.27	35.27	35.27	40.83	56.37	19.54
06:00-07:00	28.14	28.80	34.61	34.61	34.61	30.74	34.79	49.48	49.48	49.48	49.48	49.48	35.06	49.86	49.86	57.85	50.30	69.35	49.86	35.05	52.61	52.61	52.61	47.54	50.38	38.20	35.40	40.85	35.40	35.40	35.40	43.30	69.35	25.14
07:00-08:00	28.14	34.61	37.48	34.61	34.61	30.74	34.79	49.48	58.20	58.20	57.86	49.48	35.06	49.86	49.86	64.81	57.85	81.64	49.86	35.05	58.64	52.61	52.61	52.61	52.61	38.20	35.40	40.85	35.40	35.40	35.40	45.57	81.64	25.14
08:00-09:00	34.61	35.85	37.48	40.88	34.61	34.79	40.80	57.86	57.86	58.20	64.37	58.20	35.06	57.85	64.81	69.35	64.81	111.32	57.85	37.63	62.74	62.74	67.20	58.64	52.61	38.20	35.40	40.85	35.40	35.40	35.40	50.39	111.32	34.61
09:00-10:00	34.61	50.16	37.48	57.13	35.85	34.79	58.20	81.45	69.17	69.17	69.17	58.20	35.28	64.81	64.81	69.35	69.35	111.32	69.35	37.63	67.07	62.74	57.20	62.74	81.01	38.20	35.40	40.85	35.40	35.82	35.40	55.58	111.32	34.61
10:00-11:00	34.61	62.52	56.67	66.81	35.85	34.79	69.17	81.45	69.17	69.17	69.17	58.20	35.28	64.81	64.81	81.64	69.35	111.32	69.35	37.63	81.01	62.74	57.20	65.26	81.01	38.20	35.40	40.85	35.40	35.82	35.40	58.26	111.32	34.61
11:00-12:00	34.61	62.52	57.13	67.81	35.85	34.79	81.45	81.45	69.17	69.17	69.17	58.20	35.28	64.81	64.81	81.64	69.35	111.32	69.35	40.88	81.01	67.07	57.20	65.26	81.01	38.20	35.40	40.85	35.40	35.82	35.40	58.95	111.32	34.61
12:00-13:00	34.61	62.52	57.13	68.81	35.85	34.79	81.45	81.45	64.27	69.17	69.17	58.20	35.28	64.81	64.81	81.64	69.35	111.32	69.35	40.88	81.01	67.07	57.20	65.26	67.07	38.20	35.40	40.85	35.40	35.82	35.40	58.38	111.32	34.61
13:00-14:00	34.61	62.52	57.13	69.81	34.61	34.79	81.45	81.45	57.86	69.17	64.37	58.20	35.28	57.85	64.81	69.35	69.35	81.64	69.35	40.88	81.01	67.07	57.20	58.64	58.64	38.20	35.40	40.85	35.40	37.80	35.40	55.99	81.64	34.61
14:00-15:00	34.61	62.52	57.13	82.52	34.61	34.79	81.45	81.45	57.86	111.12	64.37	49.78	35.28	57.85	64.81	81.64	69.35	81.64	64.81	40.88	81.01	67.07	57.20	58.64	58.64	38.20	31.50	40.85	35.40	37.80	35.40	57.03	111.12	31.50
15:00-16:00	34.61	62.52	57.13	82.52	34.61	34.79	81.45	81.45	57.86	111.12	81.45	49.78	35.28	57.85	64.81	81.64	81.64	81.64	57.85	40.88	81.01	67.07	57.20	58.64	58.64	38.20	30.65	40.85	35.40	37.80	35.40	57.72	111.12	30.65
16:00-17:00	34.61	62.52	57.13	57.13	34.61	33.12	81.45	81.45	57.86	111.12	111.12	49.48	35.28	57.85	64.81	81.64	81.64	81.64	49.86	40.88	81.01	67.07	57.20	67.07	58.64	38.20	30.65	40.85	35.40	37.80	35.40	58.46	111.12	30.65
17:00-18:00	35.85	62.52	57.13	57.13	34.61	33.12	81.45	81.45	57.86	111.12	111.12	49.48	37.63	57.85	64.81	81.64	81.64	81.64	64.81	40.88	81.01	67.07	58.64	67.07	58.64	37.83	35.40	40.85	35.40	37.80	40.85	58.47	111.12	33.12
18:00-19:00	50.30	138.46	81.62	86.69	81.62	40.86	111.48	111.48	81.77	111.48	111.48	58.52	50.39	69.48	81.89	81.89	81.89	81.89	81.89	41.03	81.31	81.31	81.31	81.31	81.31	63.84	41.00	84.57	84.57	84.57	84.57	79.52	138.46	40.96
19:00-20:00	63.55	138.46	81.62	87.69	138.46	40.86	111.48	111.48	81.77	111.48	111.48	58.52	50.39	111.61	81.89	81.89	81.89	81.89	111.61	67.25	81.31	81.31	81.31	81.31	81.31	63.84	58.12	84.57	84.57	84.57	84.57	85.56	138.46	40.86
20:00-21:00	63.55	138.46	81.62	88.88	138.46	40.86	111.48	81.77	81.77	81.77	111.48	58.52	50.39	65.77	81.89	81.89	81.89	81.89	81.89	67.25	81.31	67.25	81.31	67.25	67.25	63.84	38.14	66.80	66.80	84.57	66.80	77.55	138.46	38.14
21:00-22:00	41.51	81.62	63.55	63.55	81.62	35.29	69.38	57.84	69.38	65.24	81.77	50.20	45.33	50.39	69.48	69.48	81.89	65.77	69.48	38.80	67.25	67.25	63.84	63.84	63.84	41.03	38.90	59.50	62.74	66.80	58.12	61.99	81.89	35.29
22:00-23:00	34.40	66.67	38.55	40.61	43.96	34.82	50.96	56.21	56.21	58.21	64.58	48.25	38.94	49.78	49.78	64.81	64.81	64.81	57.74	38.58	52.48	58.56	50.36	52.48	52.48	36.50	35.58	40.82	35.58	35.27	35.59	49.16	66.67	34.40
23:00-00:00	19.54	36.55	33.92	34.40	34.40	30.72	34.82	49.25	49.25	49.25	49.25	43.10	38.94	34.99	40.47	49.78	49.78	49.78	57.74	34.98	52.48	48.44	41.28	41.28	41.28	34.96	35.58	35.58	35.27	35.27	35.27	40.54	57.74	19.54
Daily Average	33.44	57.17	47.78	48.85	45.07	33.91	61.81	65.84	56.82	69.36	68.30	48.47	37.64	54.39	57.98	64.86	63.48	75.05	59.80	42.21	63.86	58.42	55.06	55.72	56.62	40.12	38.10	44.75	41.92	43.34	41.95	57.58	59.87	79.62
Daily Maximum	63.55	138.46	81.62	88.81	138.46	40.86	111.48	111.48	81.77	111.48	111.48	58.52	50.39	111.61	81.89	81.89	81.89	111.32	111.61	67.25	81.31	81.31	81.31	81.31	81.31	63.84	58.12	84.57	84.57	84.57	84.57			
Daily Minimum	19.54	19.54	19.54	19.54	19.36	30.72	30.72	34.82	34.82	34.32	34.82	34.62	34.89	34.89	34.89	34.89	34.39	34.89	34.89	34.96	34.96	34.96	34.96	34.96	34.96	34.96	30.65	35.27	35.27	35.27	35.27			

Source www.amm.org.gt

Table2-1-2 Interconnected National Grid (SNI): Installed Capacity (as December 2000)
国内電力供給網(SNI)傘下の設備容量

No.	PLANTS	UNITS	CAPACITY		COMMISSION	LOCATION		OWER
			INSTALLED MW	FIRM MW	DATE	MUNICIPALITY	DEPARTMENT	
	NATIONAL GRID		**1666.3**	**1420.0**				
	HYDROELECTRIC		**528.90**	**477.00**				
1	**CHIXOY**	**5**	**300.00**	**275.0**	**1983/11/27**	**San Cristobal**	**Alta Verapaz**	**INDE**
2	**AGUACAPA**	**3**	**90.0**	**75.0**	**1981/2/22**	**Pueblo Nuevo**	**Santa Rosa**	**INDE**
3	**JURUN MARINALA**	**3**	**60.0**	**60.0**	**1970/2/12**	**Palin**	**Escuintla**	**INDE**
11	SECACAO	1	15 5	13 5	1998/7/3	Senaha	Alta Verapaz	PRIVATE
4	**ESCLAVOS**	**2**	**14.0**	**13.5**	**1966/8/17**	**Cuilapa**	**Santa Rosa**	**INDE**
15	PASABIEN	2	12 0	12 0	2000/6/6	Rio Hondo	Zacapa	PRIVATE
10	RIO BOBOS	1	10 0	10 0	1995/8/10	Quebradas, Mo	Izabal	PRIVATE
16	POZA VERDE	2	8 1	8.0	2000/11/8	Pueblo Nuevo \	Santa Rosa	PRIVATE
	MICHATOYAS	**5**	**6.7**	**1.5**	**2027/10/15**	**Escuintla**	**Escuintla**	**INDE**
5	**SANTA MARIA**	**3**	**6.0**	**6.0**	**1966/6/25**	**Zunil**	**Quetzaltenang**	**INDE**
	EL JOCOTE (Cogenerador)	1	4.0	0.0	1991/2/4	Siquinala	Escuintla	PRIVATE
6	**EL PORVENIR**	**1**	**2.0**	**2.0**	**1968/9/1**	**San Pablo**	**San Marcos**	**INDE**
	CHICHAIC	**2**	**0.6**	**0.5**	**1979/7/26**	**Coban**	**Alta Verapaz**	**INDE**
	THERMAL		**1137.4**	**943.0**				
	STEAM TURBINES		221.0	177.0				
18	SAN JOSE	1	142.0	120 0	2000/1/1	Masagua	Escuintla	PRIVATE
7	**ESCUINTLA VAPOR 2**	**1**	**53.0**	**35.0**	**1977/4/22**	**Escuintla**	**Escuintla**	**INDE**
7	GGG VAPOR 3	1	13 0	11 0	1959/12/3	Amatitlan	Guatemala	PRIVATE
7	GGG VAPOR 4	1	13.0	11 0	1961/4/5	Amatitlan	Guatemala	PRIVATE
	GAS TURBINES		**301.5**	**203**				
19	TAMPA	2	80 0	78 0	1995/12/1	Escuintla	Escuintla	PRIVATE
7	GGG STEWART & STEVENSON	1	51.0	24 0	1994/12/24	Escuintla	Escuintla	PRIVATE
7	**ESC. GAS 5**	**1**	**41.0**	**30.0**	**1985/11/1**	**Escuintla**	**Escuintla**	**INDE**
7	GGG GAS 4	1	33.0	27 0	1963/6/11	Amatitlan	Guatemala	PRIVATE
7	**ESC. GAS 3**	**1**	**25.0**	**21.0**	**1976/8/9**	**Escuintla**	**Escuintla**	**INDE**
7	**ESC. GAS 4**	**1**	**25.0**	*	**1976/8/9**	**Escuintla**	**Escuintla**	**INDE**
7	GGG GAS 2	1	23.0	17 0	1978/6/19	Amatitlan	Guatemala	PRIVATE
7	**ESC. GAS 2**	**2**	**12.5**	*	**1968/5/7**	**Escuintla**	**Escuintla**	**INDE**
7	GGG. GAS 1	1	11.0	6.0	1964/6/6	Amatitlan	Guatemala	PRIVATE
	INTERNAL COMUSTION ENGINES		**422.2**	**375.8**				
17	LA ESPERANZA(ENRON POWER 3)	7	126.0	124 0	2000/5/1	Puerto Quetzal	Escuintla	PRIVATE
17	PQPC (ENRON POWER)	20	110 0	102.5	1993/2/5	Puerto Quetzal	Escuintla	PRIVATE
7	GGG LAS PALMAS	5	66 8	65 0	1998/9/1	Escuintla	Escuintla	PRIVATE
20	SIDEGUA	10	44 0	36 0	1995/4/3	Escuintla	Escuintla	PRIVATE
14	GENOR	2	42.4	40 0	1998/10/1	Puerto Barrios	Izabal	PRIVATE
	CEMENTOS PROGRESO (Autoproductor)	1	18 0	3.3	1995/11/16	Sanarate	El Progreso	PRIVATE
13	LAGOTEX	3	15 0	5 0	1996/11/15	Amatitlan	Guatemala	PRIVATE
17	PQPC (ENRON POWER)	20	120 0	102 5	2000/2/5	Puerto Quetzal	Escuintla	PRIVATE
	SUGGAR MILLS (Cogenerators)		**163.7**	**163.7**	1996/12/31	Varios	Escuintla	PRIVATE
25	PANTALEON		38 5	38 5	1995/11/16		Escuintla	PRIVATE
23	SANTA ANA		33 8	33 8	1996/11/16		Escuintla	PRIVATE
27	LA UNION		29 5	29 5	1997/11/16		Escuintla	PRIVATE
22	CONCEPCION	1	27 5	27 5	1998/11/16		Escuintla	PRIVATE
26	MADRE TIERRA		19	19	1999/11/16		Escuintla	PRIVATE
24	MAGDALENA		15 4	15 4	2000/11/16		Escuintla	PRIVATE
	GEOTHERMAL		**29**	**23.5**				
9	ZUNIL	1	24	19	1999/8/4	Zunil	Quetzaltenango	PRIVATE
8	CALDERAS	1	5	4 5	1998/11/1	San Vicente Pa	Escuintla	PRIVATE

Source: Genetec

to10, T2-1-1to10.xls/T2-1-4

2.2 Geoscientific Studies

2.2 GEOSCIENTIFIC STUDIES

2.2.1 Geological Survey

The purpose of this geological survey was to grasp the geology and structure controlling the geothermal activity through the geological reconnaissance, rock sampling and review of the existing report. The analysis was conducted by the understanding of the distribution of young volcanic bodies, alteration zones and their characteristics, heat sources and hydrogeology in the study area and its surroundings.

1. **Geological structure at the Amatitlan Area**

Guatemala is located in the northern portion of Central America, between the North American Continent and the South American Continent, bounded by Mexico on the north and Honduras-El Salvador at the south, and facing the Pacific Ocean at its southwestern side and the Caribbean Sea at its northeastern side. The Amatitlan area, which is the target area of this project, is located on the northern flank of the Pacaya volcano, 25 km far to the south from Guatemala City (Fig. 2-2-1).

The geology of this area consists of granitic basement rock, pre-caldera, syn-caldera and post-caldera volcanic rock formation, (including the Amatitlan volcanic complex consisted from dominant pyroxene andesite and subdominant dacite), the Pacaya volcanic complex and alluvium and colluvium (Fig. 2-2-2).

The geological features of the Amatitlan area are represented by caldera related faults, N-S and NE-SW faulting, and emplacement of dacitic dome. Along these structures trending, hot springs and fumaroles are located and the surface altered areas are elongated.

a. Caldera structure

The results of drilling deep exploratory wells AMF-1, -3 and -4 (West JEC and Telectro, 1995) revealed an E-W system of faults near Laguna caldera. This fault was associated to the south edge of the caldera. The geothermal fluid might be finding easy flow path through this fault system (Fig. 2-2-3).

On the other hand, many fumaroles and alteration zones are present at the north wall of the Laguna caldera. The arrangement of alteration zones and fumaroles is parallel to the western discontinuity direction interpreted from the results of gravity and MT investigations.

b. Principal fault system

The N-S fault setting is found developed in parallel direction at both sides of Los Humitos caldera. The post caldera volcanics are found altered at the west side of the western fault bounding this N-S fault system. This suggests a young geothermal activity. The west end of Los Humitos caldera has been argillized to up to a certain depth, forming a sealing zone. While the east side of the caldera shows a poor progress in alteration, suggesting a still present open fracture zone.

c. Dacitic domes

It is presumed that hot springs and fumaroles of Lake Amatitlan are originated in a fracture zone developed around the dacitic domes. However, few hot spring and fumaroles could be recognized along the fracture associated to the N-S fault system. Therefore, the fracture zone was developed at the boundary between the dome and the surrounding materials when the dacitic magma rose to form the dome. This fracture very possibly represents a path for geothermal fluid to flow. Furthermore, it is possible that this dacite dome itself is one of the heat sources in this area, considering fluid geochemistry and the formation time of the dome.

2. **Heat sources**

It is clear that the center of the volcanic activities have migrated from north to south during the geological history of the Amatitlan area from the distribution of each volcanic rock and the dating results. The hydrothermal activity is also believed to migrate in the same direction. The heat source for the geothermal activities in Amatitlan area is associated to the dacitic magmatism, including that of the still active Pacaya Volcano or to magmatic gases intrusion. This activity spans from the late Pleistocene, approximately 0.7Ma, to present. The geothermal reservoir beneath Laguna Caldera is thought to be associated to an intrusion of magmatic fluids from Pacaya Volcano.

In addition, dacitic magma's intrusion probably occurred close to Well AMF-2 some 6,000 years ago and could shape the dacitic dome body such as Cerro Limon and El Durazno acts as local heat sources.

3. **Hydrogeology**

The shallow groundwater in the study area flows from relatively high altitude zone at the north foot of the Pacaya volcano towards the Amatitlan Lake. The underground water infiltrates through the contact between the lava of the Pacaya Combined Volcano - Amatitlan volcanic complex and the pyroclastic rocks derived from the Amatitlan volcanic complex itself.

The rim of the caldera, with center at the Amatitlan lake, is conformed by normal faults. These faults are covered by thick layers of volcanic rocks derived from the activity of the Pacaya and Amatitlan volcanic complex. These faults are not inherent to the flow of the shallow underground water, but might possibly be the passage for the water to penetrate into the deeper zone. Meanwhile in the deeper parts of the system, the geothermal fluid around the faults might be easily channeled in the E-W direction but thinking on the reduced permeability orthogonal to the fault plane, the flow might be restricted in N-S direction. In the neighborhood of the area between Los Humitos Caldera to Laguna Caldera, small-scale N-W trending faults were detected. The geothermal fluids are considered to flow along the faults. These faults are clearly recognized from topographic features and it seems highly plausible that restricted to this area only both, the shallow groundwater and the deep geothermal fluid utilize the same route to flow in N-S direction. This N-S lateral flow was identified when interpreting the temperature profiles recorded at well AMF-3.

2.2.2 Geochemical survey

The geochemical survey aimed to obtain information about the geothermal fluid in the survey area for selecting the sites of exploration well drilling and for planning the future geothermal development. In order to ascertain the geochemical model constructed by the results of the previous geochemical survey, supplemental sampling and analysis of hot spring waters and fumarole gases and review of the existing geochemical information was carried out. Mercury and Radon soil-gas survey was conducted for taking information about distribution of the thermal fluid in the area with no surface manifestations or wells.

1. **Hydrogeochemical survey**

The characteristics and behaviors of hydrothermal systems in and around the survey area, inferred from the results of geochemical interpretation by this survey, are summarized as follows. The geochemical model of hydrothermal system based on the interpretation is shown in Fig. 2-2-4.

- The hot water of the reservoirs confirmed by the deep exploration wells AMF-1 and AMF-2 in Calderas sector is considered to be derived from the hot parental of 300-340℃ originating from meteoric water with minor magmatic fluid, which is stored at the south of the well AMF-2. The hot water in this sector flows mainly northeastward with steam separation, and partly ascends to shallower level producing the fumarolic fluids.

- The hot water from Calderas flows laterally toward north and northeast directions with dilution by cool groundwater, and finally reaches the south shore of Lago de Amatitlán, providing the Cl or Cl-HCO_3 type hot spring aquifers.

- The hot water from Calderas also reaches the east edge of Río Michatoya valley. The outflow of the hot water is thought to be relatively rapid, though strongly diluted.

- The hot water reservoir in Calderas is considered to have some extents in its scale, since the water seems to be in chemical equilibrium at the reservoir. If a permeable zone(s) exists from around the well AMF-2 toward the west in the survey area, the hot water reservoir may extend along that zone(s).

2. **Soil-gas survey**

From the distribution of Hg and total-Rn concentration in soil-gas, the area of hot fluid up-welling and the sub-surface structure controlling the hot fluid in the survey area are inferred as follows. The compiled map of permeable zone by soil-gas survey is shown in Fig. 2-2-5.

- Along the north caldera wall of Calderas, a permeable zone exists accompanied by hydrothermal activity; and hot fluids ascend to the shallow level at the western Calderas and around Cerro Hoja de Queso. The permeable zone in the western Calderas elongates NE-SW direction, reaching the south of El Cedro and suggesting that the geothermal reservoir confirmed by the well AMF-1 and AMF-2 extends to southwest.

- The extending direction of the moderately high Hg area around El Cedro elongating to northwest appears to have a relation with the outflow of hot water from Calderas to Río Michatoya valley which is inferred from the result of the fluid-geochemical survey.

- Permeable zones exist from around Cerro Hoja de Queso to the northwest and north, where hot fluids flow laterally at the shallow level.

- From the north of Cerro Hoja de Queso to the west of Cerro Grande, a permeable zone exists showing N-S and NE-SW trends.

2.2.3 Gravity and magnetic survey

Gravity interpretation map is shown in Fig. 2-2-6. Bouguer anomaly in the survey area (scale: 1:30,000) is shown in Fig.4-3-16. Bouguer anomaly ranges from –48.2 mgal at the north to –10.4 mgal at south of the survey area. Bouguer anomaly decreases from south to north. The iso-gravity contours strike in E-W direction at the north part of survey area in the Amatitlan low-gravity anomaly area, in NE-SW direction at the western side of San Francisco de Sales and in NW-SE direction at the eastern side of San Francisco de Sales.

The surveyed area is divided into two regions: the northern part is the Amatitlan low-gravity anomaly area and the southern part is the Volcan de Pacaya high-gravity anomaly area. Amatitlan low-gravity anomaly area is considered to reflect the caldera structure. Volcan de Pacaya high-gravity anomaly area is considered to reflect the basement uplift extending N-S direction.

Magnetic interpretation map is shown in Fig. 2-2-7. The total magnetic intensity field in the survey area ranges from 39,600 nT between the top and the southeast slope of Cerro Grande to 37,800 nT, 1 km east of Laguna de Calderas. Most part of the survey area shows a high-magnetic anomaly and a low-magnetic anomaly is recognized surrounding the surveyed area. NE-SW and ENE-WSW trend predominate in the distribution of magnetic anomalies.

The gravity lineament, west of the Volcan de Pacaya basement uplift, correspond to the magnetic discontinuity, located west of the low-magnetic anomaly at Laguna de Calderas. These are considered to reflect high permeable zone and to be very promising area for drilling for geothermal development. Because wells AMF-1, AMF-2 and AMF-3 are locate along this gravity lineament, and this is the reason for wells AMF-1 and AMF-2 to succeed in producing geothermal fluids and for well AMF-3 to show large scale lost of circulation at depth

2.2.4 Magnetotelluric survey

1. **Consideration of Magnetotelluric Survey Results**

   a. Resistivity Structure at Shallow Depths in the Survey Area

      Fig.2-2-8 shows the resistivity discontinuities (F1～F5) together with low resistivity zones showing less than 6 ohm-m obtained from the resistivity map of low resistivity layers. The low resistivity zones in this map show a relatively shallow resistivity structure roughly in the range from 200m to 700m deep.

In this map, a low resistivity zone showing less than 6 ohm-m is distributed roughly along and between resistivity discontinuity F1 and F4 excluding the area around Laguna de Calderas. Since some thermal manifestations such as fumaroles and altered zones are recognized at the ground surface in the low resistivity zone including the locations of the AMF-2 well and El Cedro, this low resistivity zone is considered to reflect a hydrothermally altered zone in the relatively shallow zone. Specifically, it is considered that the geothermal fluid coming from a deep area along fracture zones around or beneath the low resistivity zone formed the hydrothermally altered zone in the relatively shallow zone. The area around Laguna de Calderas seems to be affected by cold water coming into the caldera structure, and thus the area is a high resistivity zone.

b. Resistivity Structure at Deep Depths in the Survey Area

Fig.2-2-9 shows the resistivity discontinuities (F1～F5) together with high resistivity zones showing more than 20 ohm-m obtained from the resistivity map for a depth of 1500m. Considering the resistivity distributions in each resistivity section, the resistive zones in this map seems to reflect an uplifted structure of the resistive zone at depth.

In this map, a resistive zone is clearly distributed in the central portion, northeast portion and east portion of the survey area. And the uplifted structure of the resistive zone at depth seems to be distributed and surrounded by discontinuities F1, F4 and F5. In particular, a high resistivity zone is clearly recognized in the area between the southwest portion of discontinuity F1 (to the south of Laguna de Calderas) and discontinuity F4. Therefore, an uplifted structure of the resistive zone at depth is considered to exist between F1 and F4.

Moreover, the resistivity structure in the shallow zone described before indicates a remarkable low resistivity zone, which probably reflects a hydrothermally altered zone and which is distributed on and above the uplifted structure between F1 and F4. Furthermore, the wells AMF-1 and AMF-2 which were successfully drilled to produce geothermal fluid are located between the discontinuities F1 and F4. Therefore, it is highly probable that fracture systems are well developed along and between the discontinuities F1 and F4 and the geothermal fluid in the deep zone flows up along these fracture systems.

c. Summary of the survey results

Five resistivity discontinuities (F1 ～ F5) were obtained from the magnetotelluric survey results. In particular, a remarkable low resistivity zone which may reflect a hydrothermally altered zone is distributed along and between discontinuities F1 and F4. And the wells (AMF-1, AMF-2) which were successfully drilled to produce geothermal fluid are located between discontinuities F1 and F4. Therefore, fracture systems in the deep zone are probably developed along and between discontinuities F1 and F4 at depth.

Based on these results, we estimate that the geothermal fluid at depth flows up along the fracture systems which are located along and between discontinuities F1 and F4, and some of the geothermal fluid trapped in the relatively shallow zone is likely to form a hydrothermally altered zone along and between discontinuities F1 and F4.

In conclusion, the area along the southwest portion of discontinuity F1 (to the southwest of the Laguna de Calderas) and the area along discontinuity F4 can be recommended as promising zones for future drilling targets.

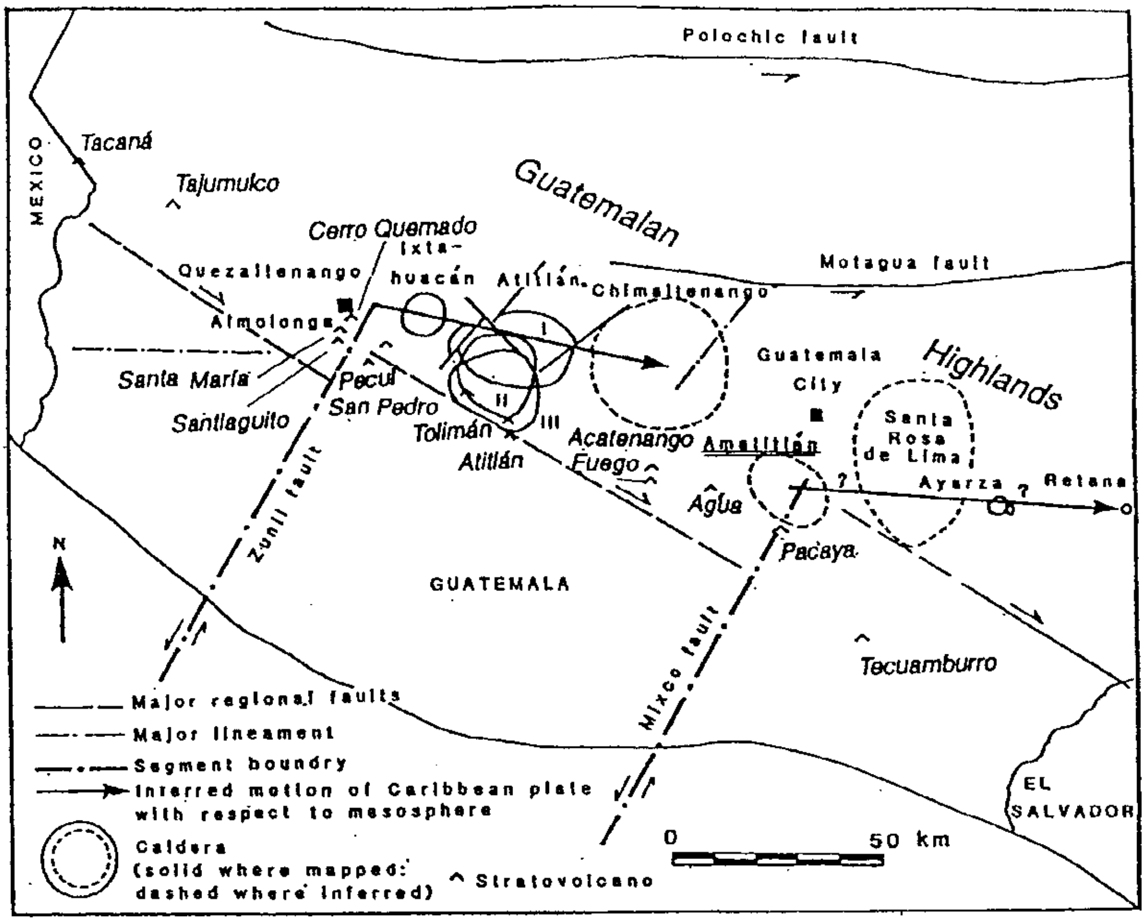
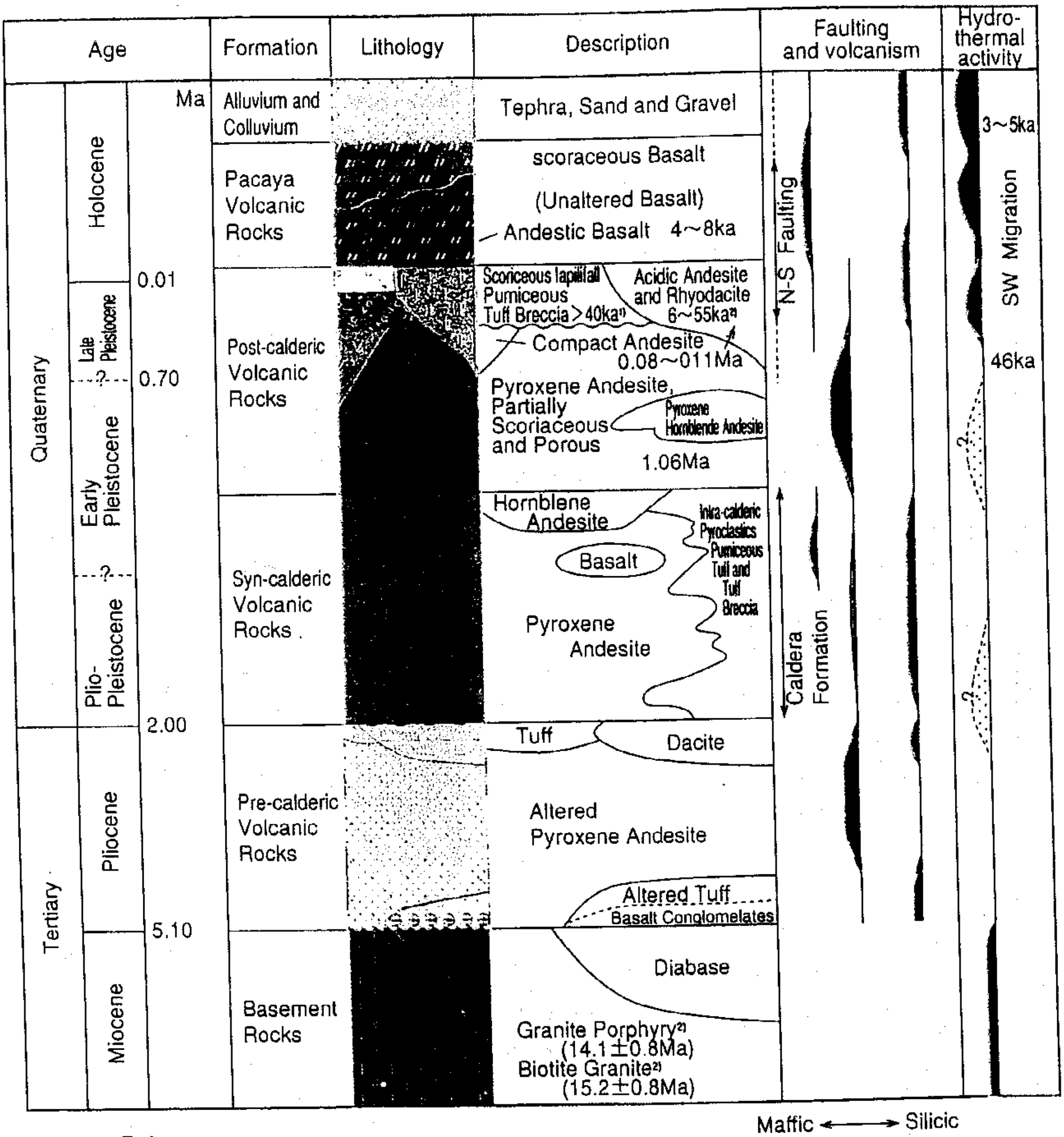


Fig.2-2-1 広域地質構造図

Regional tectonic map

Apparent migration of loci of caldera formation toward the WNW and SSW. Apparent WNW trend is interpreted as a track of calderas formed above present location of V. Almolonga, astride the Zunil fault. Apparent SSW trend is interpreted as generation of successive calderas at intersection of a proto-Zunil fault(now beneath the Atitran complex) and the volcanic front, as the volcanic front "migrated" trenchward. All migration is interpreted as a consequence of ESE movement of the Caribbean plate relative to the subduction zone and mesosphere at a rate of 0.4cm/yr.

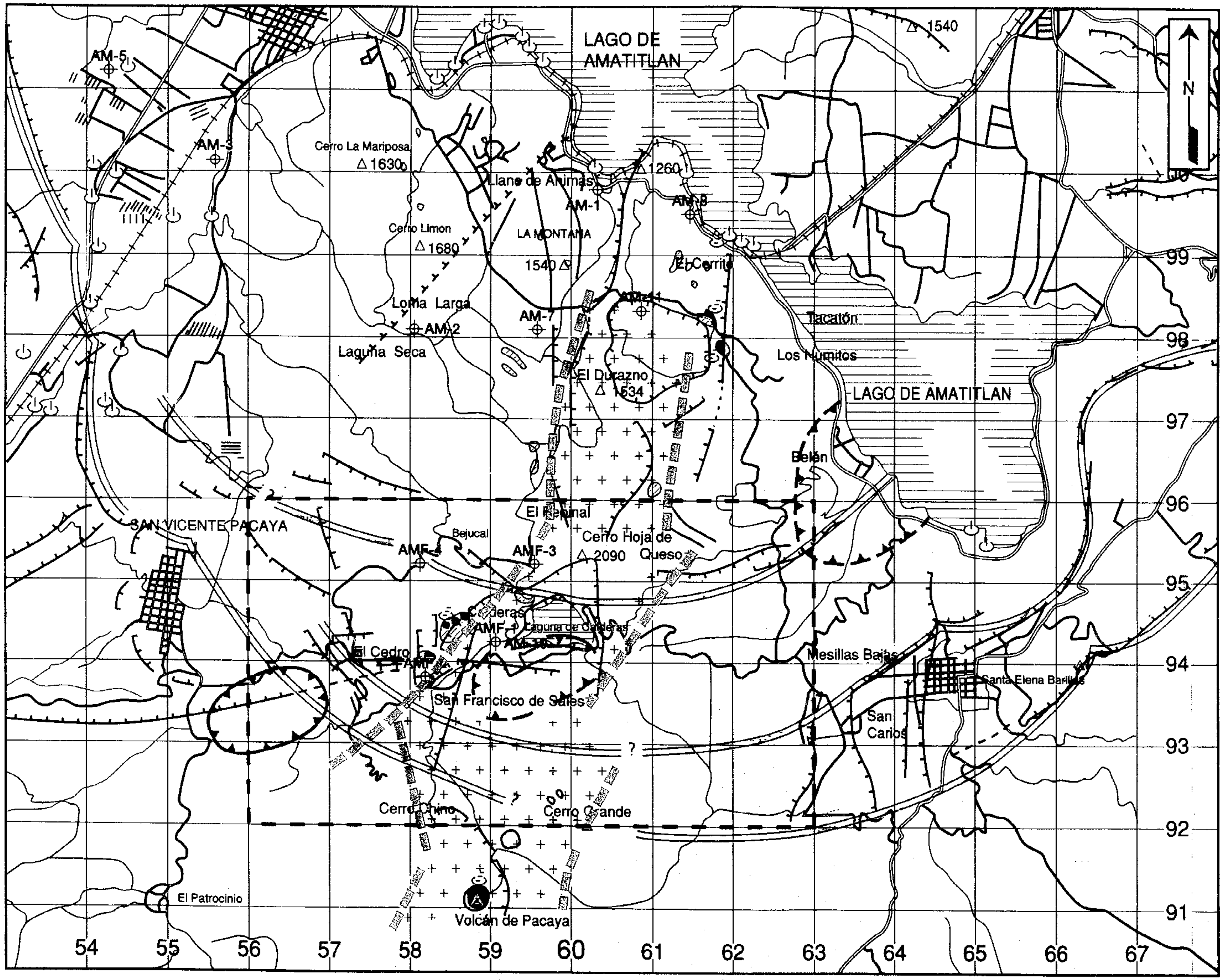
(Modified with C.G Newhall, 1987 and Vallance et al, 1995)

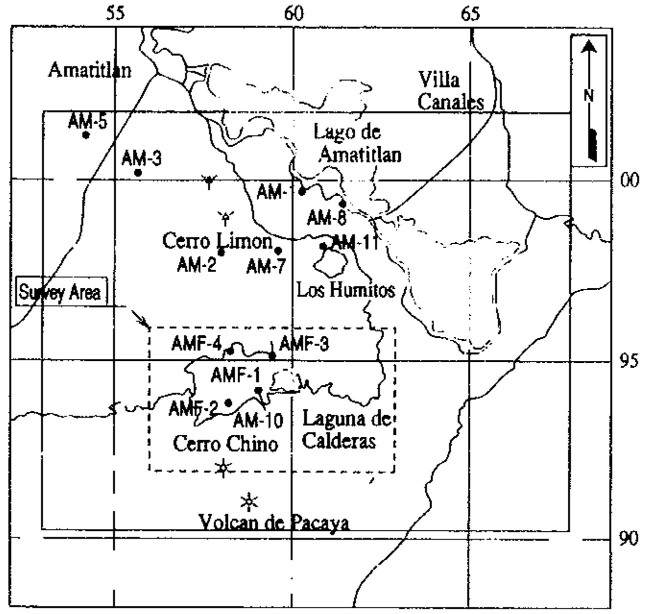


Reference
1) Koch and Mclean, 1975
2)West JEC and Telectro, 1994 and this report

Fig.2-2-2　アマティトラン地熱地域の地質層序

Stratigraphy of the Amatitlan geothermal field





Legend

Estimated uplift obtained from gravity survey

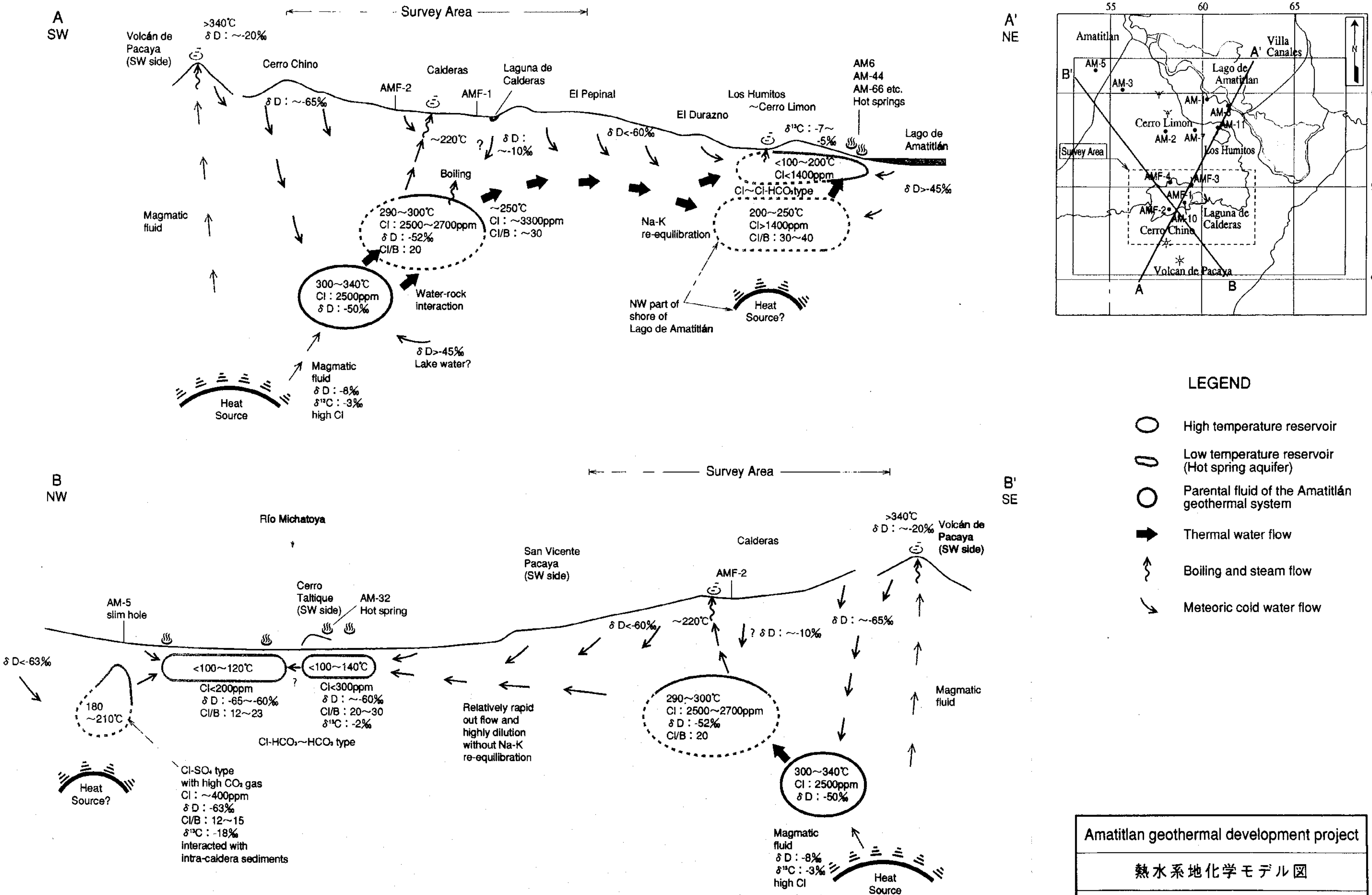
Estimated basin obtained from gravity survey

Caldera Wall

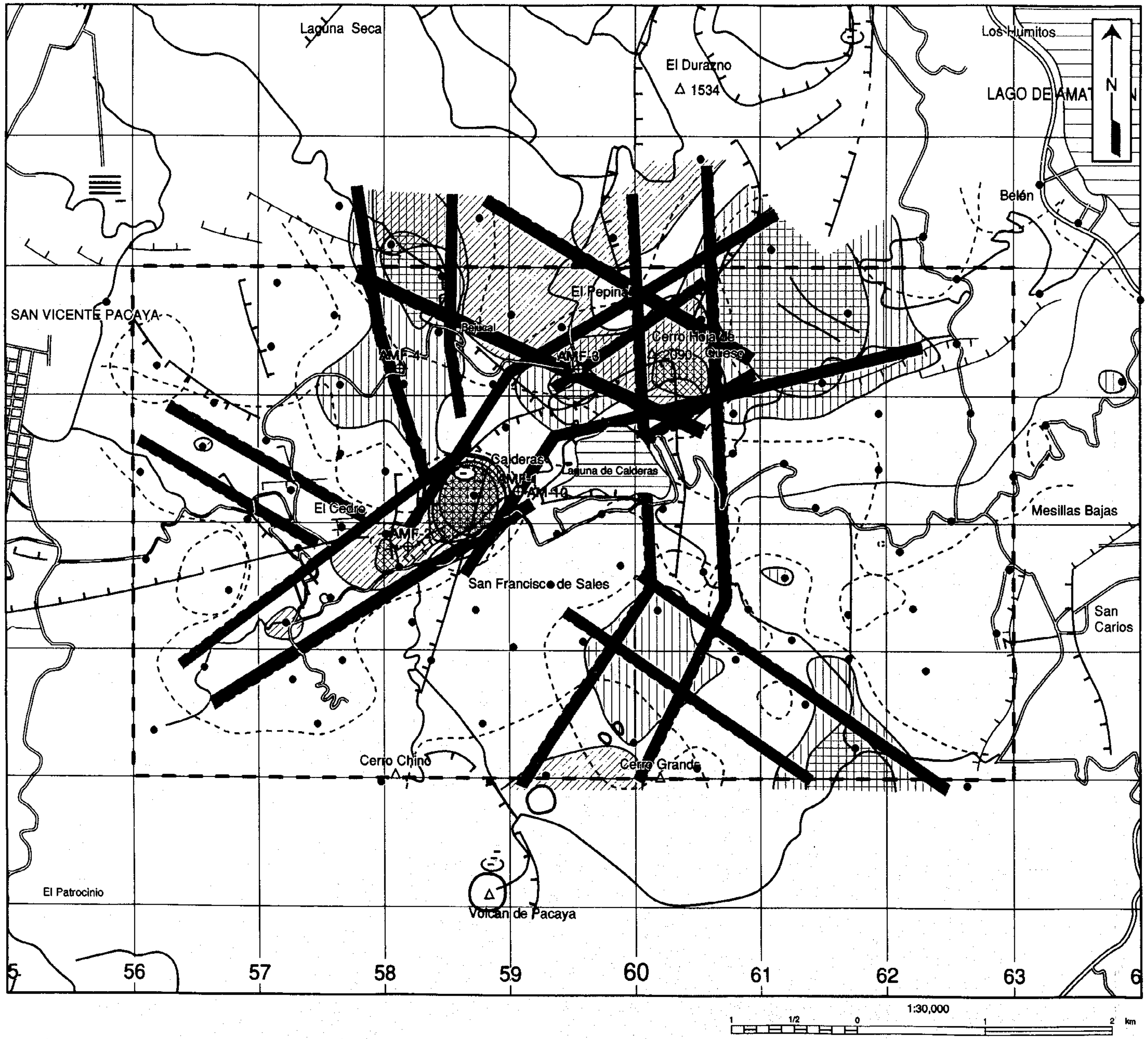
	Alteration zones, Fumarole zones		Crater
	Hot springs, Fumaroles		Phreatic Centre
	(Estimated) Fault		Lineament
A — A'	Cross section		Survey area

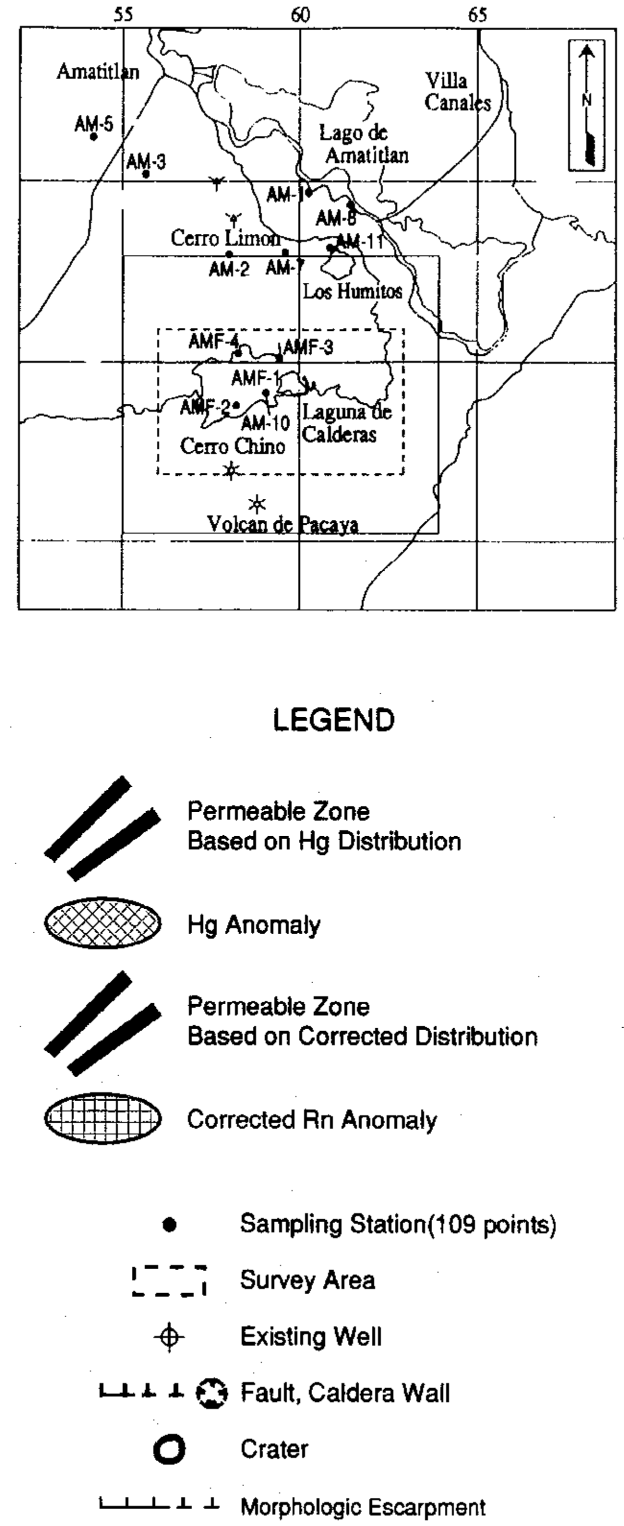
Amatitlan Geothermal Development Project
地 質 構 造 図
Geological Structure
JICA-WEST JEC — Fig. 2-2-3

M98101401A



Amatitlan geothermal development project	
熱水系地化学モデル図	
Geochemical model of hydrothermal system	
JICA-WEST JEC	Fig. 2-2- 4



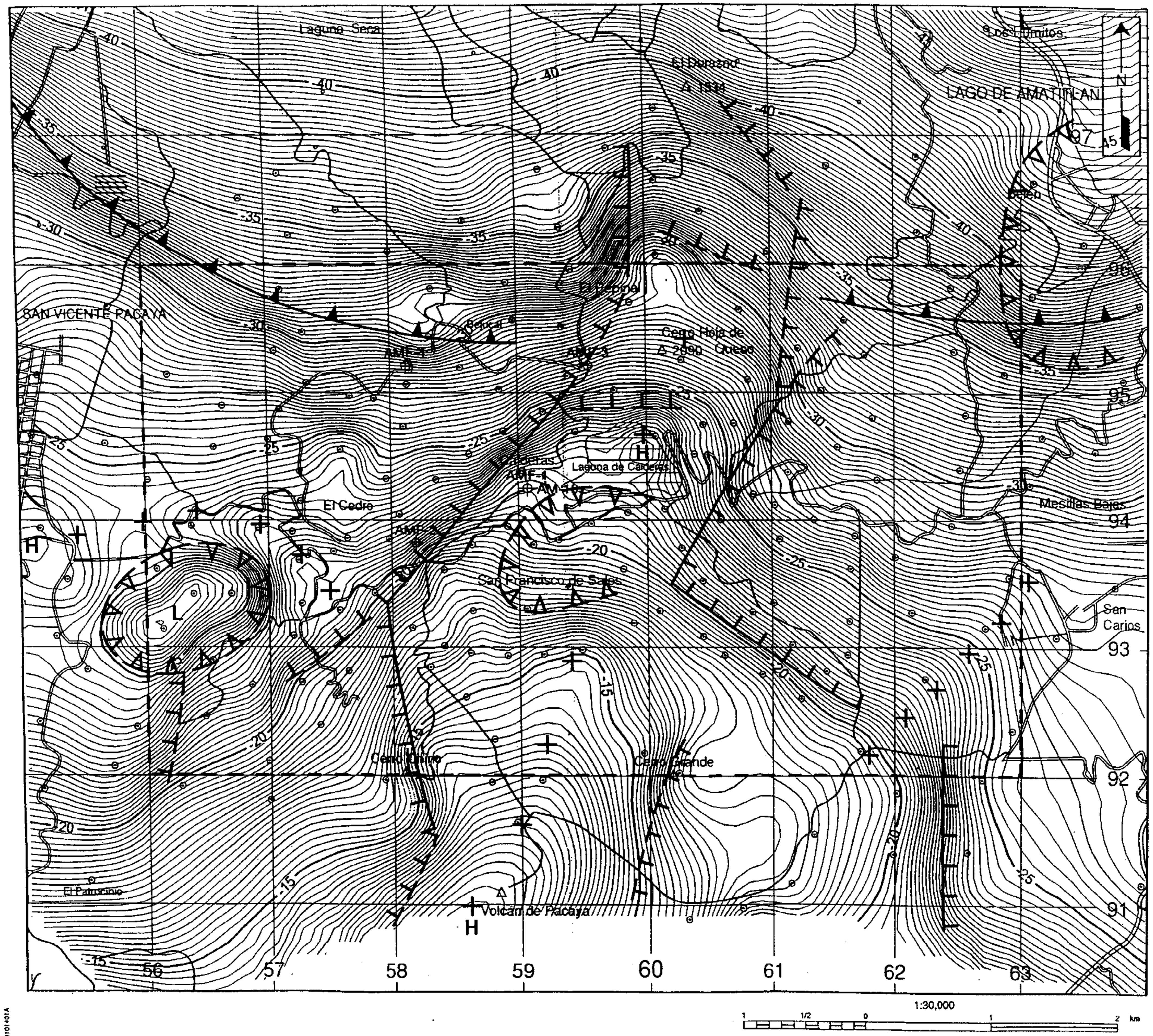


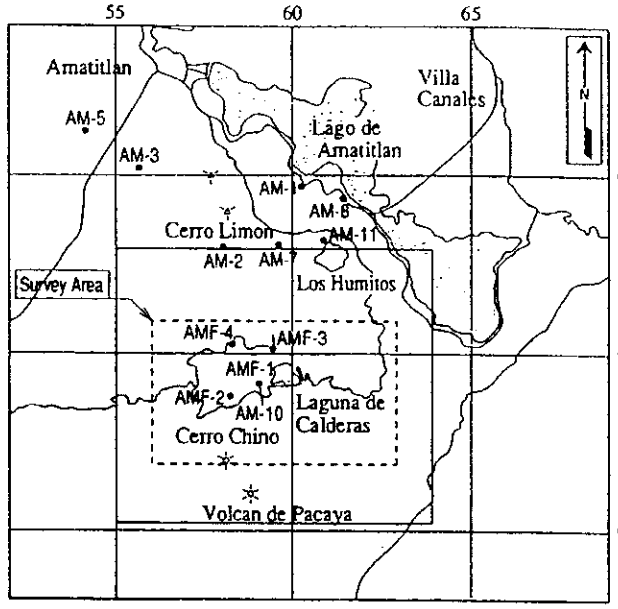
Amatitlan geothermal development project

土壌ガス調査による高透水性ゾーン集約図

Compiled map of permeable zone by soil-gas survey

JICA-WEST JEC | Fig. 2-2-5





Legend

: Survey Area

: Exploratory Well

: Caldera Rim Estimated from Gravity

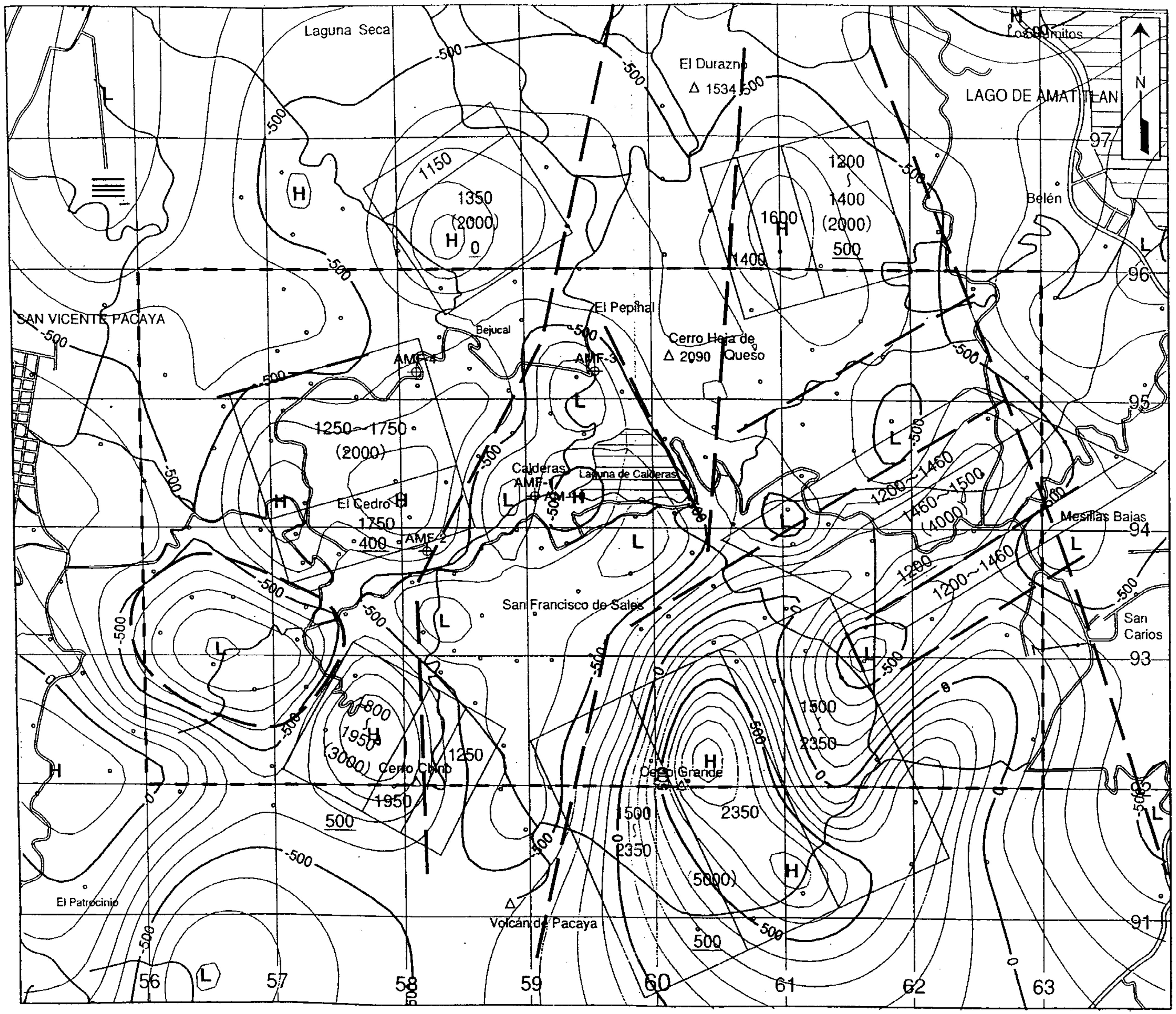
: Basin

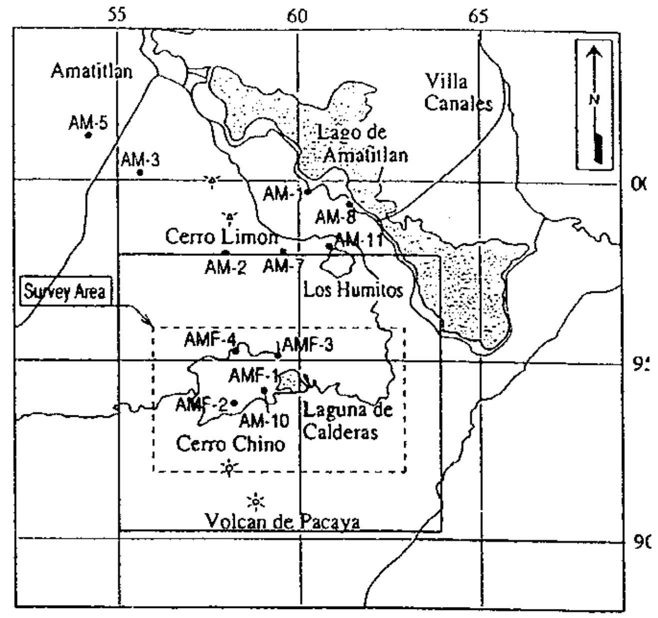
: Gravity Lineament(major)

: Gravity Lineament(minor)

: Basement Uplift trend

Amatitlan Geothermal Development Project	
重力解析図	
Gravity Interpretation Map	
JICA-WEST JEC	Fig.2-2-6





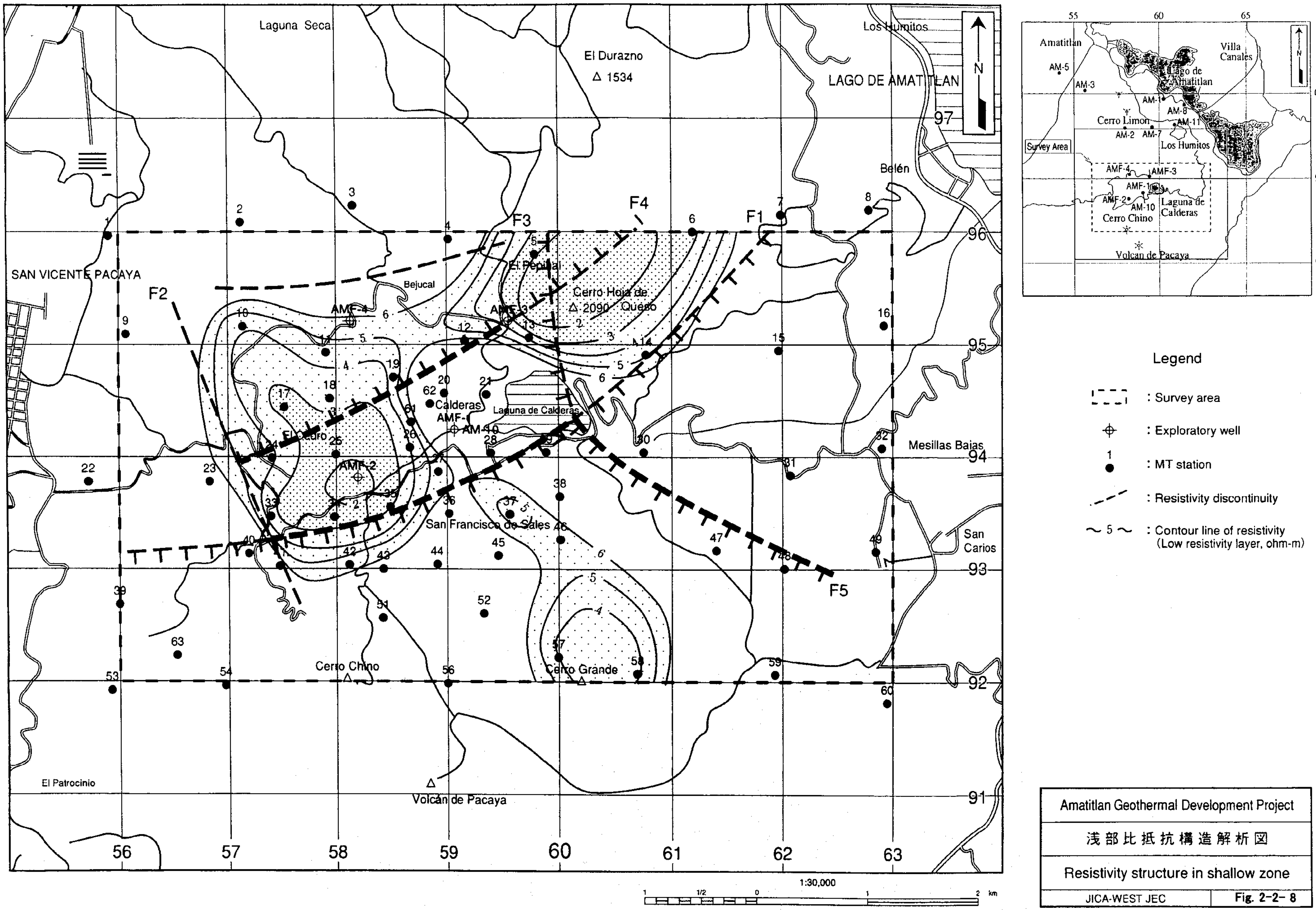
Legend

- Survey Area
- Exploratory Well
- Magnetic Discontinuity
- Magnetic Body
- 1600 : Top Depth of Magnetic Body
- (2000) : Magnetic Susceptibility ×10^{-6}emu/cm^3
- <u>500</u> : Bottom Depth of Magnetic Body

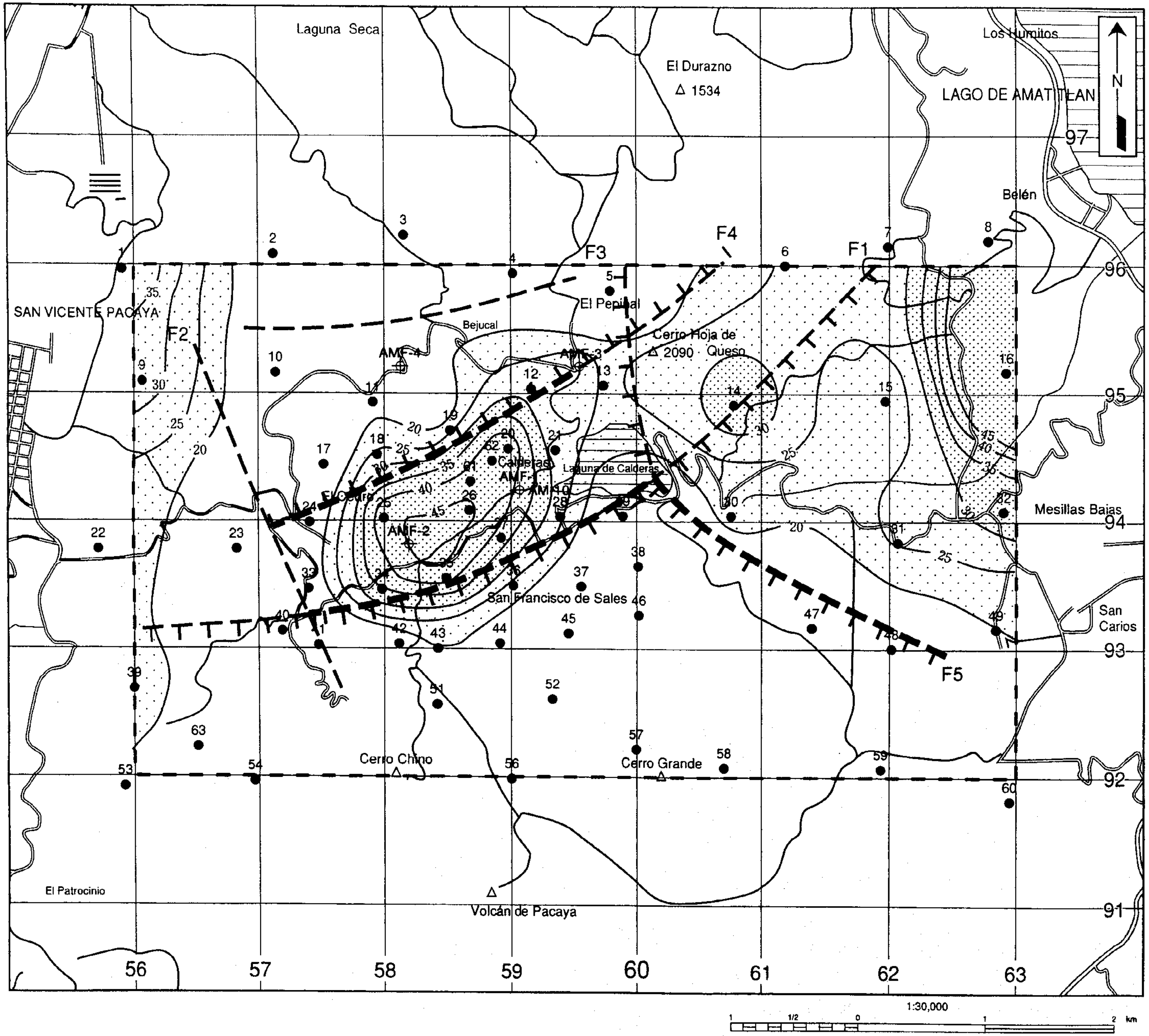
1:30,000

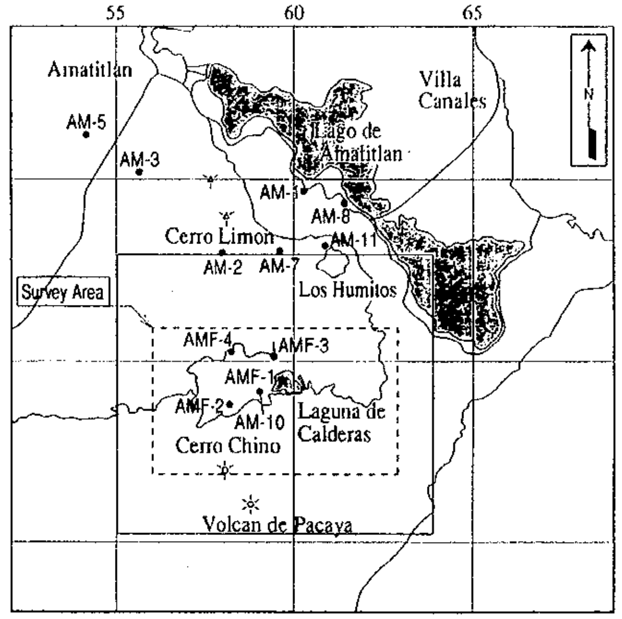
1 1/2 0 1 2 km

Amatitlan Geothermal Development Project	
磁気解析図	
Magnetic Interpretation Map	
JICA-WEST JEC	Fig.2-2-7



Amatitlan Geothermal Development Project	
浅部比抵抗構造解析図	
Resistivity structure in shallow zone	
JICA-WEST JEC	Fig. 2-2- 8





Legend

- : Survey area
- : Exploratory well
- : MT station
- : Resistivity discontinuity
- ~20~ : Contour line of resistivity (Resistivity distribution at 1500m deep)

Amatitlan Geothermal Development Project	
深部比抵抗構造解析図	
Resistivity structure in deep zone	
JICA-WEST JEC	Fig. 2-2- 9

2.3 Exploratory Well Drilling

2.3.1 Well AMJ-1

2.3.2 Well AMJ-2