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GEOHERMAL POWER DEVELOPMENT

RESOURCE EVALUATION ASPECTS

FOR

KYUSHU ELECTRIC POWER COMPANY

FUKUOKA, JAPAN

[Handwritten signature]

Donated By:
Herbert Rogers Jr.
Rogers Engineering Co.

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30 OCTOBER 1980

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GEOTHERMAL POWER DEVELOPMENT
RESOURCE EVALUATION ASPECTS

for

KYUSHU ELECTRIC POWER CO., INC.

FUKUOKA, JAPAN

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30 OCTOBER 1980

Prepared by

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JOB NO. S-80002

KYUSHU ISLAND GEOTHERMAL AREAS

KYUSHU ELECTRIC POWER

DRAWING NO.

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1.0

INTRODUCTION

This report is a limited review of and presents comments on the geothermal resource exploration program of Kyushu Electric Power Company (KEPCO). This program is for developing geothermal resources to generate electric power on Kyushu Island, Japan. Many organizations in Japan and in particular Kyushu Electric Power Co., Inc. are actively exploring for and developing geothermal resources on Kyushu Island. KEPCO has already demonstrated an ability and expertise to explore for geothermal resources by their successful exploration and subsequent development of several fields (Hatchobaru and Otake) on the island of Kyushu for electric power generation.

The review and comments are made relative to the geothermal resource aspects of Kyushu Electric Power Company's geothermal exploration program, and within the time, budget, and scope of the Rogers Engineering's effort under the existing contract. Rogers and its consultants have had a wide variety of geothermal exploration experience and have used such experience in the analysis of what has been presented by KEPCO.

The remainder of the introduction section develops general knowledge concerning geothermal power development with particular emphasis on the resource exploration. The data received section describes the information available to perform the project work. There are no interpretative parts to the data received section. The philosophy section relates our understanding of the KEPCO thinking and conditions surrounding current geothermal resource development in Japan. The survey and methods sections presents three important items about each study KEPCO has performed in the resource exploration program. These three aspects are: what should be obtained from the method, what data was obtained and presented, and what is a review and analysis of where the KEPCO exploration program is currently in terms of progress and successful location of reservoirs. The final section presents recommendations on the many aspects of the resource exploration for geothermal power development.

1.1

Geothermal Characteristics

This section addresses general geothermal characteristics which must be recognized for utilization in power plants. Geothermal resources include hot dry rocks, geopressure, dry steam, and hot water systems. The latter two resources result from a magmatic heat flow into confined underground water systems. The energy transport fluid may be discharged as dry steam, steam and water (two phase flow) or as hot water. If the predominant reservoir fluid is dry or superheated steam, it is termed a vapor-dominated system. If the predominant fluid is liquid water, it is termed a liquid-dominated system. The

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latter is the most frequently found resource based on exploration results to date. For a liquid-dominated system the least quality resource for power generation that appears economical to exploit based on available technology today is one with a downhole (reservoir) temperature in excess of 325°F, a salinity of less than 50,000 ppm or carbonate content of less than 550 ppm.

All geothermal fluids contain noncondensable gases. The content by weight may be as high as 10 percent but generally is about 2 percent. These noncondensable gases normally include CO₂, H₂S, NH₃, H₂, N₂, and various hydrocarbons. Hydrothermal fluids with high salinity levels (35,000 ppm or greater) are generally classified as brines. These brines contain a silica content which is directly relatable to the well's downhole fluid temperature, and may contain high concentrations of the salts of boron, arsenic, and the heavy metals.

The resource is produced for use through suitable wells. It is delivered to the surface by the available reservoir pressure, in combination with "in-well" flashing steam. Deep well turbine pump delivery of geothermal fluids may be quite attractive since flashing, and attendant problems such as salt deposition, well plugging, etc. can be minimized. However, fully developed hardware is not yet available for pump settings below 1,000 feet handling water in excess of 350°F.

The temperature of a geothermal resource downhole, for use in the generation of electricity must be greater than 163°C and preferably greater than 220°C. It must also have an adequate source of water with access to the heat source and sufficient permeability to permit its extraction by conventional well drilling and completion techniques. Such high temperature, shallow geothermal reservoirs that have been discovered to date are located near the margins of crustal plates, where scientists consider that the interaction, subduction and overriding, of these large plates and the subsequent frictional sliding of these large continental land masses, one against the other, produce hot molten rock which is able to move upward in the crust mainly due to the increased faulting and fracturing associated with these regions.

The geothermal reservoirs currently being exploited for electric power generation have few common geological characteristics. For example, the Geysers field in northern California, U. S. A. is producing steam from fractured graywackes and siltstones; the Larderello field in northern Italy is producing steam from carbonate rocks; the Wairakei field in New Zealand is producing hot water from volcanic rocks; and in the Imperial Valley, California and the Cerro Prieto, Mexico fields are producing hot brines from alluvial and deltaic

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sediments. Similarly the geophysical characteristics of these geothermal areas vary widely. The knowledge gained from these areas indicated that an exploration program must therefore emphasize flexibility in the approach to geothermal exploration.

1.2

Exploration Standard Program

This section presents a logical plan for a resource exploration program - one that has proven to be effective, efficient in the time required to produce electric power at the bus, and also is cost effective. This plan will be called the "Standard Program" and will be used as a reference to evaluate the KEPCO program. The Standard Program for resource exploration has five phases: Exploration, Exploration Results Report, Exploratory Well Drilling, Well and Reservoir Testing and an Exploration Summary Report. These phases are described briefly in the following paragraphs.

A geothermal resource, in its most basic sense, consists of an underground heat source at depth, an overlying confined, permeable geologic formation with access to circulating hot fluids through an appropriate "plumbing system", and an impermeable cap formation to contain the hot fluids. More specifically, the resource exploration program objectives are to locate these hot areas, to estimate the volume, temperature, and permeability at depth; to predict the type of production; and to estimate chemical composition of the produced fluid.

The program should locate and delineate the resource, estimate its area and volume, develop a reservoir model, evaluate its energy content, and assess the commercial value of the resource. This program should develop such data and knowledge so as to reduce development risks.

A large uncertainty in estimating the thermal energy in a reservoir is the area and volume of the reservoir. In only a very few geothermal systems has the approximate area and volume of the reservoir been determined solely by drilling. Indirect evidence must also be used to estimate the area and volume for nearly every system. All available geologic, geophysical and geochemical data must be used to develop estimates of the thermal energy and reservoir models of these systems. The exploration to locate and delineate this resource is therefore of prime importance to the ultimate development of geothermal energy.

It is very evident from experiences of other geothermal fields around the world, no given area or prospect is exactly similar to

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the next, and therefore, no one exploration technique or combination of techniques will suffice in all situations. A given method or survey design may be useful or informative in one area but is not in another. Even with this individual diversity there is a general format that is common to almost all exploration programs. This format involves a logical progression of exploration stages that would progress from the less expensive and/or less sophisticated techniques to the more costly and complex exploration techniques. A well-founded and fiscally responsible resource exploration program in a geothermally promising region should follow a well-planned sequence for focusing effort on the most promising areas, in order to produce the optimum results at a minimum of time and cost.

1.2.1 Exploration

The first steps in the exploration phase must be reconnaissance in nature and planned to locate areas with a local heat source and the presence of vertical conduits that will provide plumbing sufficient for the water movement that is required to transport the heat from deeper sources. Geologic history, tectonic setting and a thorough surface examination of thermal occurrences will define potential areas for geophysical surveys.

This exploration phase should start with a low cost general reconnaissance survey of the region of interest. A successful conclusion of the reconnaissance phase would result in the identification of one or more attractive geothermal areas of interest.

The exploration of an area of interest should be made employing an appropriate selection of geological, hydrological and geophysical survey methods carried out at a semi-detailed spacing or precision. A successful conclusion of the area exploration should result in the identification of one or more "prospects", or highly promising local areas, for more detailed study.

The next step of the exploration phase is the detailed study of the prospects. This exploration would involve those techniques that have been determined appropriate for the unique set of conditions that have theretofore been revealed for each prospect and the application of other techniques that are more cost effective or useful in this phase. The successful conclusion to this phase of the resource exploration program would be to write a report of exploration results or prefeasibility.

Drawing 1-1 shows graphically the exploration terminology used and quantifies these terms in terms of size. It depicts the focus required to progress through the phases.

REGION

REGION: KYUSHU ISLAND (4.3×10^6 HECTARES)
 AREA OF INTEREST : 200-400 KM² (2×10^4 TO 4×10^4 HECTARES)
 PROSPECT: 10-30 KM² (1,000 TO 3,000 HECTARES)
 DRILL SITE : 6000 SQ. METERS (0.6 HECTARES)

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1.2.1.1 Regional Evaluation

The evaluation of a region is performed to locate areas of interest and to establish the initial data base for future exploration endeavors. This survey is performed to determine the regional tectonics and geology, areas of interesting surficial thermal manifestations, previously performed exploration surveys, other information that may be useful in determining prospective areas and as an aid in future exploration efforts.

Information that can be useful for this stage of the exploration program are all available literature, maps, publications, and other information on the geology, topography, geophysics, geochemistry, hydrology, meteorology, cultural features, vegetation, access highways, general land ownership, and other data that may be useful for present or future exploration efforts. Also useful is analysis of satellite imagery for at least the entire region of interest.

This portion of the exploration program may only receive a small percentage of the exploration budget but the quality and thoroughness of the efforts expended at this stage of the exploration program can have a strong impact on the overall program.

1.2.1.2 Area Evaluation

The evaluation of an area(s) of interest is undertaken to locate potential prospect(s), delineate potential geothermal reservoir(s), establish the framework of the area and to establish the data base for further exploration efforts. In this stage of the exploration program those methods that are felt to be cost-effective when applied to an area on a semi-detailed reconnaissance bases will be utilized. Some other methods may be applied here also to test their usefulness or effectiveness in future exploration programs in this particular environment. The area evaluation must survey the entire areas so as to provide a representative sampling of the subsurface as well as being detailed enough to delineate potential prospects.

1.2.1.3 Prospect Evaluation

The evaluation of a prospect(s) within an area is undertaken to delineate the potential reservoir, and locate drill sites for testing, calibrating, and evaluating the surface geophysics and for testing the reservoir. Many of the methods utilized in this portion of the exploration program will have already been used in the area exploration stage and hence non-applicable methods will be disregarded and survey designs and parameters will be improved from the knowledge gained from these area surveys. The data acquired in this stage will be very detailed and will be targeted initially at pros-

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pective zones delineated by the area exploration. As this data is evaluated additional work may be warranted to further detail and delineate prospective features. These surveys need to be designed so that sufficient useful data is acquired to aid in understanding the exploratory well information and hence in defining and understanding the reservoir or geothermal system. This data is very important in determining the area and potential volume of the system and for reservoir modeling studies.

1.2.2 Exploration Results (Preliminary Feasibility)

Prior to exploratory well drilling careful and detailed analysis of the data gained from the various exploratory techniques used will be undertaken by the exploration management team. This will involve intergration and correlation of results of the geologic, geohydrologic, geochemical, geoelectric and other geophysical surveys, and the thermal gradient studies.

Upon completion of each individual survey a separate final report should be produced for each exploratory discipline or technique. A composite "Exploration Results Report and Prefeasibility Study" should then be compiled which will correlate all the findings and produce appropriate hypothesized geologic models of the reservoir showing the stratigraphy, volcanologic and tectonic history, geohydrology and heat source.

The Prefeasibility Study should identify a number of proposed drill sites for production size exploratory wells, with a priority schedule and "decision tree" listing the criteria for future decisions to be made as the drilling results evolve. The criteria should include the types of geologic formations expected to be encountered, the depth and types of formation fluids, the permeability and/or extent of fractures in the target reservoir, and the temperatures to be encountered at critical depth points. These criteria will provide the basis for decisions, at critical points, of whether to drill ahead or to abandon a given borehole.

The Prefeasibility Study should also outline a program for extension of the exploration efforts, if warranted, such as expanding the boundaries of the zone of interest, or more detail to better refine the well site selection process.

1.2.3 Exploratory Well Drilling

The drilling of several exploratory wells is the next phase of the resource exploration program provided the exploration results report provided sufficient data and reasoning to establish the drill sites. These drill sites are the most prospective places to drill and

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penetrate the potential reservoir. Funding for five full sizes production wells should be available as three successful wells are needed for the next phase of the program.

At the completion of each well, full well drilling and geologic reports should be made. These must include all logs, and must correlate the geological and geophysical data obtained to the reservoir model developed in the exploratory results report. Each new exploratory well site should be reevaluated with the then present data prior to starting to drill.

1.2.4 Well and Reservoir Testing

At least three exploratory wells successful in penetrating the geothermal reservoir are necessary for this phase of the resource exploration program. They must be judiciously located to measure the reservoir characteristics when produced. These well and reservoir tests will be used to evaluate the potential for further development of the reservoir and the usefulness of this reservoir for electric power production.

1.2.5 Exploration Summary (Technical Findings)

At the end of the well testing phase of the production size exploratory wells, the entire exploration program should be summarized in a formal report of Technical Findings. This report should summarize the history of the project, evaluate all of the technical data developed, and offer conclusions as to the existence of an apparent commercial geothermal resource.

A key part of this report should be the evaluation of the geologic and geophysical results of the borehole drilling. This section should first give a summary description of the initial conceptual model of the reservoir, and then it should describe how the actual subsurface conditions revealed by the drilling have altered the reservoir model. It should make generalized predictions of the areal extent and depth of the productive reservoir formation, the nature and location of the heat source, and the mechanics (permeability and/or fractures) and hydraulics of the fluid system.

Also included in this report should be a drilling summary which should review the history of the drilling activities from an engineering viewpoint. The drilling and completion experience of the exploratory wells should be evaluated, and recommendations should be made that could improve the efficiency of these operations in the development phase.

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A report of the methods used and the results obtained in the flow testing of the exploratory wells should be included. This should present the measured flow rate of the geothermal fluids, the percentages of steam, hot water, and noncondensable gases, and the chemical analysis of the dissolved solids. The data from this report will provide the basis for geothermal power plant design, and for environmental controls and waste fluid disposition.

1.2.6 Resource Evaluation

The resource evaluation is the next step in the overall Standard Program and follows the resource exploration step. The complete overall Standard Program is outlined in Section 1.3. The resource evaluation makes a reservoir assessment and improves the reservoir model with the data available from the resource exploration step. At the completion of well drilling, flow testing, and resource assessment, a report will be prepared on the technical and economic feasibility of generating electric power from this resource. In addition to resource considerations, a power study of the region should be made to determine load centers, demand growth, and line voltages and capacities, in order to establish the appropriate size of the geothermal power plant installation.

1.3 Overall Standard Program

The overall standard program for geothermal development is presented here to give the standard program for resource exploration a perspective. The standard program regarding the resource exploration was presented in detail in Section 1.2 so it can be compared to the status of exploration by KEPCO. The relationship of the resource exploration step to the overall development program is important and must be recognized in terms of effort, time and money.

1.3.1 Program Sequence

An outline of the overall program sequence follows. It is in order by time, except C and D run concurrently. Section A was described in detail in Section 1.2 of this report as the Standard Program. Sections A & B take approximately one-half the total time; however, it should only expend about eleven percent of the total budget.

- A. Resource Exploration
 - A-1 Exploration
 - A-2 Exploration Results (Prefeasibility)
 - A-3 Exploratory Well Drilling
 - A-4 Well and Reservoir Testing
 - A-5 Exploration Summary

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- B. Resource Evaluation
 - B-1 Reservoir Assessment
 - B-2 Power Station Feasibility
 - B-3 Overall Feasibility
- C. Resource Production Development
 - C-1 Continued Exploration
 - C-2 Well Spacing
 - C-3 Production Well Drilling
 - C-4 Well Testing
 - C-5 Injection Wells
 - C-6 Gathering and Injection Systems
- D. Power Station Development
 - D-1 Site Selection
 - D-2 Final Design
 - D-3 Major Equipment Purchases
 - D-4 Construction
 - D-5 Transmission

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1.3.2

Standard Geothermal Development Program Budget

An estimated budget is presented to show the monetary strength of each section of the overall Standard Program, (use 215 yen per dollar to convert currencies).

A. Resource Exploration

Exploration	\$ 1,200,000	
Site Develop (5)	150,000	
Exploration Test Wells (5)	5,000,000	
Well Testing (3)	261,000	
Subtotal	\$ 6,611,000	
Management Allowance (15%)	1,131,000	
Subtotal	\$ 7,742,000	
Contingency (20%)	1,587,000	
Budget		\$ 9,290,000

B. Resource Evaluation

Resource	\$ 70,000	
Feasibility Study	130,000	
Subtotal	\$ 200,000	
Management Allowance (5%)	10,000	
Subtotal	\$ 210,000	
Contingency (10%)	20,000	
Budget		230,000

C. Resource Production Development

Exploration	\$ 500,000	
Site Prep (12)	360,000	
Production Wells (12)	12,000,000	
Injection Wells (6)	3,600,000	
Well Testing	300,000	
Subtotal	\$16,760,000	
Management (10%)	1,680,000	
Subtotal	\$18,440,000	
Contingency (15%)	2,760,000	
Budget		21,200,000
Gathering & Injection System		6,250,000
Subtotal		\$36,970,000

D. Power Plant Development

Power Plant - 50,000 kW		44,700,000
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Total Standard Geothermal Development Program		<u>\$81,670,000</u>
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DATA RECEIVED

Resource exploration data for our project work was received in three stages. The first stage was receipt of three evaluation reports with accompanying figures. These were reviewed prior to the second stage of data receipt which was a two week trip to Fukuoka to discuss data and visit the major exploration and production sites. The third set of data received was additional written materials concerning exploration aspects. Each set of data is described briefly in this section. No analysis or evaluation of this data is in this section.

This report makes the assumption that the data received comprises substantially all of the data base in the possession of KEPCO for their geothermal exploration. The conclusions and recommendations made herein are based on that assumption. Furthermore, this report does not undertake to evaluate the quality of any of the surveys and studies that are included in the data base furnished, since these materials were not available for review.

2.1

Potential in Kyushu

The report titled "Report on Evaluation of Geothermal Potential in Kyushu" by West Japan Engineering Consultants, Inc., 1980 is a brief summary of exploration areas and anticipated prospects for the island of Kyushu. The purpose of this report was to present the evaluation of geothermal resources on Kyushu Island and to estimate the potential for development in terms of megawatts of potential power plants. It was based on existing data as of July 1980. This report also was to assist in developing a geothermal development plan.

The figures provided totaled 12 and were entitled as follows:

<u>Figure</u>	<u>Title</u>	<u>Area</u>
A- 2	National Park & Forest Regulation	Hohi I
A- 3	National Park & Forest Regulation	Hohi II
A- 4	National Park & Forest Regulation	Unzen
A- 5	National Park & Forest Regulation	Aso
A- 6	National Park & Forest Regulation	Kirishima

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A- 7	National Park & Forest Regulation	Satsunan
A- 8	Summary of Exploration Data	Hohi I
A- 9	Summary of Exploration Data	Hohi II
A-10	Summary of Exploration Data	Unzen
A-11	Summary of Exploration Data	Aso
A-12	Summary of Exploration Data	Kirishima
A-13	Summary of Exploration Data	Satsunan

The majority of this report is presented in table format and consists of three tables which are briefly described.

2.1.1 Geothermal Areas

Table 1 is a "List of Geothermal Area" (Prospects). This table basically lists the surface restrictions such as national parks, etc. for each of the six areas. The restrictions within these areas are categorized according to the anticipated prospects outlined within each area.

2.1.2 Evaluation Data

Table 2 is entitled "Evaluation of Exploration Data" and is a listing, for each of the six areas according to the designated prospects within these areas, of the exploration methods (no detailed description), evaluations (very brief) derived from these methods, and the empirical ranking of these prospects.

2.1.3 Evaluated Potential

Table 3 is a table of the "Evaluation of Geothermal Potential" which lists the anticipated MW potential for each anticipated prospect according to a maximum 50 MW capacity for each 2 square kilometer prospect based on the percentage amount of the anticipated prospect area that is not restricted.

The areas (prospects) to be evaluated (2 km²/area were selected from each geothermal region, taking the geothermal manifestations, topographical condition and dwelling houses in the areas into consideration. The numbers of areas (prospects) selected for evaluation in each region (area) are as follows:

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<u>Area</u>	<u>Prospect</u>
Hohi Region	17 areas
Unzen Region	8 areas
Aso Region	4 areas
Kirishima Region	12 areas
Satsunan Region	8 areas
Total	49 areas

The geothermal potential evaluation is summarized by the following chart in terms of megawatts potential generation.

	<u>Hohi</u>	<u>Kirishima</u>	<u>Unzen</u>	<u>Aso</u>	<u>Satsunan</u>	<u>Total</u>
Geothermal Potential Total:	425	412	100	87	100	1,124
National Park Lands:						
Outside Park	146	103	25	0	88	362
Common Area	79	234	54	54	0	421
Special Area 2nd Class	200	75	21	33	12	341
Special Reserve Area	0	0	0	0	0	0
Regulated Forests:						
National Forest	78	221	34	0	0	333
Reserved Forest	162	151	0	8	0	321
Private Housing:	12	0	3	4	2	21
Bad Topographic Areas:	39	26	15	2	3	85

2.2

Exploration in Hohi

This report is entitled "Report on Evaluation of Geothermal Exploration in Hohi" by West Japan Engineering Consultants, Inc. 1980. It covers aspects of the exploration endeavors in the Hohi I and Hohi II areas. This report is a brief summary of the exploration endeavors itemized by designated prospects for these two areas. The figures provided total 15 for Hohi I and Hohi II areas. The figures for the Hohi I area are entitled as follows:

<u>Figure</u>	<u>Title</u>
B- 2-1	Aerophoto Analysis Map
B- 3-1	Geological Map
B- 4-1	Bouguer Gravity Survey
B- 5-1	Residual Bouguer Gravity Survey
B- 6-1	Electrical (VES) Exploration
B- 7	Electrical (S. P.) Exploration
B- 8	Magnetic (H) Survey
B-12-1	Summary of Exploration Data
B-13-1	Scope for Additional Exploration

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The figures for the Hohi II area are entitled as follows:

<u>Figure</u>	<u>Title</u>
B- 2-2	Aerophoto Analysis Map
B- 3-2	Geologic Map
B- 4-2	Bouguer Gravity Survey
B- 5-2	Residual Bouguer Gravity Survey
B- 6-2	Electrical (VES) Exploration
B- 9	Ground Temperature Survey
B-10	Geochemical (Hg) Exploration
B-12-2	Summary of Exploration Data
B-13-2	Scope for Additional Exploration

The majority of the report is presented in table format and the tables are briefly described as follows:

2.2.1 Existing Data

Table 1 is a table of "Summaries of Existing Data" and lists for each anticipated prospect in the Hohi I area, the exploration methods utilized together with a brief outline of the exploration's result(s).

2.2.2 Exploration Results

Table 2 is a table of "Evaluation of Exploration's Results" which lists each designated prospect with a brief evaluation and the basis for the evaluations.

2.2.3 Future Exploration (KEPCO)

Table 3 is a table of "Future Explorations for the Project Areas (Prospects) of KEPCO" and lists each designated prospect and the type, anticipated cost, and purpose of various exploration methods proposed to be utilized for future evaluation of these prospects.

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2.2.4 Future Exploration (Others)

Table 4 is a table of "Future Explorations for the Project Areas (Prospects) of other Developers" and is a very brief listing of what KEPCO wants to do. In prospects which developers other than KEPCO are developing it gives what KEPCO might require from a developer in terms of future exploration, drilling, assessment and development.

2.2.5 General

The Hoho region is approximately 84,000 hectares and the exploration area is about 10,500 hectares. There are 17 prospects 200 hectares each, defined in the report for Hoho. 13 prospects are defined for KEPCO to develop and the remainder are designated for others to develop. KEPCO budget proposes an exploratory well for all but one prospect and gives a recommended order for the drilling. The prospect well drilling order is as follows: 1, 5, 6, 7, 8, 9, 10, 14, 15, 16, 3, 4.

KEPCO proposes a future exploration budget as follows:

	<u>Survey</u>	<u>Million Yen</u>	<u>Thousands \$</u>
1.	Geochemical	112.5	523
2.	Radiometric	79.5	370
3.	Electrical (Self Potential)	48.	223
4.	Electrical (Resistivity)	280.	1,307
5.	Microearthquakes	9.	42
6.	Ground Temperature	325.	1,512
7.	Wells (12)	<u>4,800.</u>	<u>22,326</u>
	Future Exploration Budget Total	¥ 5,654.	\$26,298

2.2.6 Other Developer Proposed Criteria

The proposed criteria for other developer's are presented from the report and are as follows:

- 1) Geochemical Exploration (Hg Method)
The objects are to measure the Hg density in soil air and soil and to invest the magnitude and distribution of probable structural lines.
- 2) Radiometric Survey (Gamma Ray Intensity)
The objects are to measure the natural gamma ray intensity, and to investigate the magnitude and distribution of probable structural lines.

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- 3) Electrical Exploration (Self Potential Method)
The object is to investigate the distribution of negative potential zones.
- 4) Electrical Exploration (Resistivity Sounding Method)
The objects are to investigate the distribution of low resistivity layers, and to find out discontinuities of resistivity layers.
- 5) Drilling of Exploratory Well
Exploratory wells by all coring; four wells.
All exploratory wells should succeed to produce geothermal fluid.
- 6) Drilling of Production Well
30% of the necessary steam amount for planning power output must be confirmed.
- 7) Synthetic Analysis
The development of the necessary steam amount for planning power output must be sufficiently assumed from the synthetic analysis of the explorations' results and the results of exploratory wells and production wells.
- 8) Conditions of Location
The construction of power station will not be restricted by national park regulations and forest regulation, etc.
The construction of power station will not be restricted by access road condition, water supply, etc.

2.3

Exploration in Kirishima

This report is for the area of Kirishima and is similar to the Hohi report in format. It is entitled "Report on Evaluation of Geothermal Exploration in Kirishima" by West Japan Engineering Consultants, Inc. 1980. This report covers aspects of the exploration program in the Kirishima area. The 14 figures for this report are entitled as follows:

<u>Figure</u>	<u>Title</u>
C- 2	Aerophoto Analysis Map
C- 3	Geological Map
C- 4	Hot Water and Gas Analysis

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<u>Figure</u>	<u>Title</u>
C- 5	Geochemical Exploration (Hg)
C- 6	Bouguer Gravity Survey
C- 7	Residual Bouguer Gravity Survey
C- 8	Distribution of Microearthquake Epicenters
C- 9	Ground Temperature Survey
C-10	Electrical (VES) Exploration
C-11	Electrical (S. P.) Exploration
C-12	Radiometric (1975) Survey
C-13	Radiometric (1979) Survey
C-15	Summary of Exploration Data
C-16	Scope for Additional Explorations

The majority of this report is presented in table format and a brief description follows:

2.3.1 Existing Data

Table 1 is a table of "Summaries of Existing Data" and lists for each designated prospect in the Kirishima area, the exploration methods utilized together with a brief outline of the exploration's result(s).

2.3.2 Exploration Results

Table 2 is a table of "Evaluation of Exploration's Results" which lists each designated prospect with a brief evaluation and the basis for the evaluations.

2.3.3 Future Exploration (KEPCO)

Table 3 is a table of "Future Explorations for the Project Areas (Prospects) of KEPCO" and lists each designated prospect and the

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type, anticipated cost, and purpose of various exploration methods to be utilized for future evaluation of these prospects.

2.3.4 Future Exploration (Others)

Table 4 is a table of "Future Explorations for the Project Areas" by other developers.

2.3.5 General

The Kirishima region is approximately 84,000 hectares and the exploration area is about 10,000 hectares. There are 12 identified prospects, 200 hectares each, defined in the Kirishima report. Six prospects are defined for KEPCO to develop and the remainder are designated for others to develop. The KEPCO budget proposes to drill 5 additional wells over and above the seven already drilled. The proposed drilling prospect sequence is: 1, 2, 4, 5 and 7.

KEPCO proposes a future exploration budget as follows:

<u>Survey</u>	<u>Million Yen</u>	<u>Thousands \$</u>
1. Geochemical (Hg Method)	39.6	184
2. Radiometric	27.3	127
3. Electrical (Self Potential)	22.2	103
4. Electrical (Resistivity)	34.7	161
5. Wells (5)	<u>2,000.0</u>	<u>9,877</u>
Future Exploration Budget Total	2,123.8 ¥	\$9,877

2.4 Trip Discussions

The second stage of the data received consisted of discussions during meetings between Rogers Engineering and KEPCO in Fukuoka and a field trip between September 1, 1980 and September 11, 1980. Included in these meetings was a three day field trip on September 6, 7, 8, 1980 around the island of Kyushu and specifically to project areas Hohi I, Hohi II and Kirishima. Much information was exchanged and transmitted verbally in these meetings. Concepts discussed included resource ownership; government policy, or lack of it, towards geothermal development; discussions of each exploration area and survey method; discussions of Otake and Hatchobaru; reservoir modeling; steam pricing; and other topics.

The subjects discussed were concepts of reservoir ownership, political incentives and impediments to geothermal development, and general background to the exploration program. Some observations made during the meeting were that without definition of resource owner-

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ship an exploration and exploitation policy would be difficult to formulate. KEPCO explained that in Garan two different development companies are exploring in the same areas, and there was discussion of the relative efficiency of this method.

2.4.1 Discussions on Hohi Area

The history of exploration and development of the Otake geothermal prospect area was discussed. Otake exploration began in 1950; land purchased by KEPCO in 1964 expedited development. The reservoir is in tuffs and breccia with many fissures at about 500 meters in depth. The exploration in this area was initiated based on the many active fumeroles and hot springs present. The Otake plant was online in 1967.

In Hatchobaru the reservoir is from a deeper reservoir in fractured rocks at the basement interface. The shallow rocks of the Otake reservoir are at Hatchobaru but faults appear to seal any hot fluid circulation. The deeper reservoir at Hatchobaru may be present below Otake but drilling has not gone this deep.

The reservoir capacity of these two fields has not been estimated yet. They have experienced injection problems at these plants. Injection wells cooled production wells and therefore the injection wells had to be relocated and redrilled. Fluorescent tracer tests were performed to determine circulation after problems developed. Low magnetic anomalies correspond to alteration zones based on resistivity soundings. Alteration zones determined by X-ray analysis of surface and well samples.

The self-potential surveys were utilized in this area to delineate areas of low acidity so as to place injection wells and avoid sealing. Depth resolution and lateral problems, of Schlumberger soundings, exploration policy, objectives and philosophy were also discussed.

The policy of KEPCO is to extend Otake and Hatchobaru, then development of the Kirishima common zone, and then development of the Garan area. Land restrictions and problems associated with these were also reviewed.

2.4.2 Discussions on Kirishima Area

Discussions were begun on the Kirishima area exploration program. KEPCO feels that they have completed surface exploration and are now in the exploratory well drilling stage of the exploration program. Exploratory holes are not production size wells. In Kirishima,

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KEPCO and Nippon Steel have arbitrarily divided the survey area. They do not share data and exploration surveys cannot cross the boundary.

2.4.3 Other Discussions

The rectangles that are labeled as prospects, 1 x 2 km, are for plant areas and are based on philosophical power plant site conditions rather than on exploratory data. These 'prospects' are based on anticipated field size to support 50 MW plant, on topography and access, land restrictions, and on presumed (not proven) reservoir locations.

Briefly discussed costs of exploration, but these were difficult to determine since exploration has been carried out over many years, since 1950, and were obtained in many different ways such as from university, contractor, etc. We were unable to get past budgets or expenditures for Hohi or Kirishima exploration.

2.5 Additional Material

The third stage of data received consisted of copies of publications, maps, cross sections and data that were made available during the meetings in Japan between KEPCO and Rogers.

These included papers entitled:

- 2.5.1 "Development of Geothermal Power Generation in Otake and Hatchobaru Area", September 1980 by Y. Kinoshita.
- 2.5.2 "Geothermal Energy Utilization in Japan", Japan Geothermal Energy Association, 1974.
- 2.5.3 "Proceedings of the United States - Japan Geological Surveys Panel Discussion on the Assessment of Geothermal Resources" Geological Survey of Japan, October 27, 1975.

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- 2.5.4 Appendix A - Development history of geothermal energy related to the Kyushu Electric Power Co., Inc.
- 2.5.5 Table - brief history of geoscientific surveys in Otake and Hatchobaru (1 page)
- 2.5.6 Publication unknown -
Sec. 2-2 Distribution of Volcanoes of the Quaternary Period
Pages 8, 9, 12, 13, 14, 15
- 2.5.7 "Development of Geothermal Power Generation in Otake and Hatchobaru Area", Oct. 5, 1978. K. Tanaka
- 2.5.8 Publication-No title; on the Otake Geothermal Development
- 2.5.9 "On the Development of the Otake Geothermal Field" Katsundo Kubota-1976.
- 2.5.10 "Evaluation of the Geothermal Potential of Kirishima by resistivity sounding curves" by Gerland Buttacavoli and Seibe Onodera, Memoirs of the Faculty of Engineering, Kyushu University, Vol. 39, No. 1, 1979.

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2.5.11 Publication unknown - "Japan, Otake, Sec. 6.3, pages 133 through 144" and "Japan, Hatchobaru, Sec. 6.6, pages 154 through 165".

2.5.12 Data from Vertical Electrical Soundings by Schlumberger Methods at Garan - 20 sounding locations and electrical cross sections for lines A and B.

2.5.13 Exploratory Well Logs - Kirishima Area

<u>Figure</u>	<u>Title</u>
14-1	Well KT-1
14-2	Well KT-2
14-3	Well KT-3
14-4	Well IIM-1
14-5	Well IIM-2

2.5.14 Exploratory Well Logs - Hohi Area

<u>Figure</u>	<u>Title</u>
11-1	Well HT-1
11-2	Well HT-2
11-3	Well HT-3
11-4	Well HT-4
11-5	Well 53-GR-1
11-6	Well 51-WT-1

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3.0

PHILOSOPHY

The basic theory concerning Kyushu Electric Power's geothermal resource exploration program is presented from our understanding of the KEPCO thinking. In general, at the beginning of a new legal and technology area, the initial philosophy will be speculative. Based upon further inquiry and knowledge gained by experience the philosophy will develop into a basic system of thinking about the subject. The geothermal resource exploration program should reflect the ideas the company has on the subject. The most important elements of the present thinking will be addressed.

3.1

Exploration

The philosophy and goal of the geothermal exploration program as stated by KEPCO is to develop a resource in as timely a manner as possible. This involves locating a resource outside of the national park boundaries, obtaining resource ownership or production rights by drilling, and developing a single 50 MW electric power plant.

3.1.1

Area Exploration

The process of selecting areas to explore for geothermal resources has not been presented to be determined primarily by geothermal exploration activity. It appears to be dominated by relative position with respect to other developers, land ownership and presence in an area.

3.1.2

Prospect Exploration

On all the exploration maps are power plant prospect rectangles. These rectangles 1 x 2 km, are for plant areas and are based on philosophical conditions of plant siting rather than on exploratory data. These 'prospects' are based on anticipated field size to support a 50 MW plant, topography and access, land restrictions, and anticipated (not actual) reservoir locations. This was used in estimating the megawatt potential of Kyushu Island and appears to dictate exploration surveys and plans.

3.1.3

Reservoir Size

Based upon the past exploration, Kyushu Electric Power's derived theory is that reservoirs in Japan are not very large but are instead limited to approximately 450 to 500 meters wide and 1 km long. They also feel that there could be 2 reservoirs that are 1 to 2 km from each other that are completely and totally separate.

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3.2 Influencing Factors

The exploration philosophy has many influencing factors. The most salient factors are here presented to give background for the previously stated position.

3.2.1 Power Production

Kyushu Electric Power's main business line is the generation, transmission and distribution of electric energy to the electric users on Kyushu Island. Geothermal resource exploration is undertaken by the power company in the development of electrical generation methods which are economic and displace imported fuels currently used in electric power production.

Geothermal power plants are planned to be economic in 50 MW capacity increments. The electrical demand growth per year requires approximately 500 MW additional capacity be installed per year on the Kyushu Electric Power System. One geothermal plant is therefore only about 10 percent of the required additional capacity. Proven geothermal reservoir capacity on Kyushu is not sufficient to construct 10 fifty megawatt geothermal plants per year at this time. Geothermal power plants will be constructed when economic and reservoirs are available.

3.2.2 National Circumstances

In 1979, there was a Tokyo Energy Summit Conference. As a result of this conference, Kyushu Electric Power Company has been allocated 263 MW of geothermal electric power plant capacity to be built by the year 1985. This is roughly 25 percent of the national goal of 1,000 MW. Kyushu presently has 63 MW and therefore is striving to meet the allocation with 200 MW of new plants.

The only national law relating to geothermal production deals with regulating Hot Springs administered by the local prefecture governments. The ownership of the reservoir is very important to the development of geothermal. This is a major problem which must be resolved before monies should be spent on exploration.

Geothermal reservoirs should be developed on geological and geophysical characteristics to insure minimum cost and equitable production. Unit agreements should be made to join all area parties together for a given reservoir exploration and production. This should be a national policy to prevent waste. No such agreement type is now in existence nor is it required by national law.

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3.2.3 Hot Springs

Japan has many hot springs and national legislation regulated by local prefecture hot springs committees establishes orders and permits for their use. As these hot springs are used by many businesses and individuals they should not be destroyed by geothermal power plant production. Generally speaking the power plant geothermal production would be from lower reservoirs which should not effect hot springs. However, there is a large quantity of hot water left over after the power plant use which can be made available to hot springs users, if necessary.

The leftover hot water from the power plant is typically of the same quality as that in the hot springs. Only specific projects can actually determine the relationship to the hot springs use; however, power plant production should be stimulated provided that hot springs use is not curtailed or if curtailed it should be replaced by use of the leftover hot water from the power plant.

The national legislation relates the reservoir production to the hot springs use at this time in the development of geothermal resources.

3.2.4 National Lands

The national government in Japan as in other countries controls a portion of the land as land owner. There are many categories and reasons for this ownership. Three categories of national land are covered by the National Park law: Special Reserve, Special Area and Common Area. These subdivisions each have special rules and regulations. The Special Reserve area is the most restricted area and is totally removed from geothermal development considerations.

Geothermal development areas are sought after to be outside national parks and on private land. The Environmental Protection Agency with MITI has agreed to allow six existing geothermal developments within special areas; however, at this point in geothermal development leasing of national lands with special restrictions and regulations has not been allowed or implementing methods established.

Many national parks require special status because their creation was determined by the presence of young or active volcanism or because of geysers, fumaroles or hot springs which are surface evidence of high temperature convection systems. Current policy is to completely eliminate these areas from any and all exploration activities. This is to ignore what may be a very critical under-surface connection of geothermal resources between national park areas and contiguous private areas.

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3.2.5

Ownership

Ownership of the geothermal reservoir is a dominant feature in the development plan and the willingness of individuals or companies to invest monies in exploration. Unless the ownership question is resolved waste of money and resource will occur because of competition on a single reservoir. The surface land owner also has a role in the exploration and production. It is most logical and consistent with private enterprise to have the surface land owner be the owner of that portion of the reservoir under his land surface. This policy allows a one source, landowner, agreement to develop the reservoir without conflicts between owners of surface and subsurface rights.

Irrespective of surface ownership, restrictions, etc. the reservoir must be understood in order to be properly developed. All of a reservoir may not be available for development because of these restrictions, but the extent, thickness and other parameters related to the reservoir and to development still need to be determined. An exploration philosophy must therefore recognize political restraints and access and development restrictions but must nevertheless proceed to evaluate the total reservoir irrespective of these constraints.

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4.0

METHODS AND SURVEYS

The evaluation procedure used in this report is to relate, or compare, the preceding work already accomplished and the future work planned to a "Standard Program" for a typical geothermal exploration effort as used in other countries. Only approaches used by KEPCO are presented and reviewed.

The evaluation of each method or survey type will be made by the following systematic approach:

- (a) State what the method or type of survey can and should generally accomplish.
- (b) State the degree of precision of the survey required for each phase (region, area, prospect) exploration.
- (c) Describe what has been done to date, and what is planned, (so far as can be determined), under KEPCO program data.
- (d) Review and comment on program data as related to the Standard Program.

4.1

Literature Search

There should be a careful evaluation of all existing data on the geology, climatology, hydrology, topography and geophysics of the region. This should be carried out simultaneously with the field reconnaissance. This evaluation should consider completeness and reliability of the data, and should identify gaps to be filled in forthcoming exploration. It should result in preparation of a detailed statement of exploration needs and likely techniques to be employed to provide the needed data.

4.1.1

Program Data

Much data of a background nature appeared to be available though there did not appear to be a concise library or catalogue system present for rapid and efficient retrieval and utilization of this data. It appeared that this data was diffused throughout the participating organizations and disciplines involved, with no central repository or person responsible for maintaining, cataloging and updating the data base.

4.1.2

Data Review and Comment

From the data available and the discussion during meetings with KEPCO, it appears that some good efforts were made in this area. Unfortunately much of the documentation, cataloging and central filing system necessary for a geothermal project of this magnitude were not evident. It appears that many individuals, disciplines and

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organizations have the necessary information, documents, data, etc. but that no individual or group has been given the responsibility for collecting, coordinating, cataloging and disseminating this information. It is felt that a person should be placed in charge of these functions as well as being responsible for having general knowledge of the content of these reports, etc. He/she should also be charged with updating and upgrading this data base by contacts with universities and other organizations that may have information useful to the effort.

4.2 Satellite Imagery and Aerial Photography

Satellite imagery is a very useful regional reconnaissance method as well as an aid in the study of an area of interest. The interpretation of these photos could be used to find major and some minor lineaments, faulting, geologic features or boundaries, terrain, vegetation, alteration zones, possible superficial thermal zones by infra-red photography, etc. These images can be a very inexpensive and cost-effective regional and area exploration method.

Aerophoto analysis (1:15,000 to 1:40,000 scale) is an important stage in the early phases of an exploration program. The quality of the photographs in terms of flight elevation, camera angle, clarity, time of year, etc. are all important aspects to the quality of the final interpretation. These aerial photos can aid in the structural and geologic mapping and analyses as well as an aid in survey planning. The use of these photos is most applicable to the area exploration stages of the exploration program.

4.2.1 Program Data

The photos for the survey areas under consideration in central Kyushu, Hoho I and II areas, were acquired in 1970 at a scale of 1:40,000 on a black and white positive. The photos were analyzed with a stereoscope by Prof. T. Murai of Tokyo University. We did not view the photos or discuss acquisition in any detail. The interpreted data from these surveys was presented on plan view maps.

The data depicted active faults and dip, lateral faults and probable faults and/or lineaments.

The photos for the western half of the Kirishima volcanic Zone were acquired in 1979 by KEPCO AND Prof. H. Urota of Kyushu University. The photos were black and white positives printed from 1:15000 color negatives and analyzed by Prof. Urota with a stereoscope. The more detailed 1:15000 data for Kirishima indicated the locations of geologic lava flow boundaries, and/or dip change lines, collapse or sharp cliffs, younger collapse cliffs, faults and dip, lineament

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and/or fracture trace, main drainage, and altered zones. The smaller scale 1:15000 aerial photos appear to show greater detail than the larger scale 1:40000 photos and the comparison between these surveys may be useful in determining parameters for use in planning, implementing and interpreting future or additional surveys.

4.2.2 Data Review and Comment

It appears that the very recent volcanics on Kyushu decreases the usefulness of this method and therefore in planning, strong consideration must be given to the cost effectiveness of this method.

There was no indication that the satellite imagery was used in the geothermal resource exploration program. All of the images should have been obtained for the island of Kyushu and analyzed both individually and as a composite mosaic of the island. Larger scale images should be examined more closely for the individual areas. Clear mylar overlays of the interpretation of these should be made as well as of geology, faulting and other features of interest. These images can be very useful for a regional and area evaluation and are generally very cost effective.

Aerial photography is a very useful exploration tool in the initial and in later stages of an exploration program. It appears that these photos were well utilized in the exploration program. If smaller scale photos exist for Hohi, such as the 1:15000 photos available in Kirishima, or if the 1:40000 photos were of such a quality that they can be enlarged, this would be very helpful. If they had to be reflown then this would probably not be cost effective. These photos should also be cross correlated with the results of the satellite imagery. These photos should aid the geologic mapping program.

If it has not yet been done, the interpretation of these photos should be refined by the geologic mapping and from other methods. Exploration should be a continual process of reiteration, summing, reinterpretation and reevaluation. Color as well as black and white photos should be used. In Hohi only black and white photos were available but in Kirishima and other prospects black and white photos were used from color negatives. Both should be used. It would also be useful to have these photos available with the interpreted features marked and delineated on these photos.

4.3 Geological Survey

A geological survey should begin with the literature search, aerial photos and office planning and mapping, and should progress to field studies, first on a regional scale and then on to more detailed area

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and prospect mapping surveys. The aim of these surveys is to delineate thermal areas, such as alteration zones and hydrothermal deposits and structural features (such as intersecting fault or fracture systems) that are favorable to the development of geothermal systems. The emphasis, therefore, should be on the tectonic and stratigraphic settings of the area, recent faulting, the distribution and age of young volcanic rocks, and the location and character of thermal manifestations such as hot springs, fumaroles and hydrothermal alteration zones.

For the regional geologic studies, semi-detailed mapping is usually adequate. After an area of interest has been identified, its geology should be mapped in greater detail.

4.3.1 Program Data

From the data made available to us it is difficult to determine the regional geologic evaluations, though papers such as "Geothermal Energy Utilization in Japan", "Proceedings of the United States-Japan Geological Surveys Panel Discussion on the Assessment of Geothermal Resources" and a paper on the distribution of volcanoes of the Quaternary Period indicate that some regional analysis was considered though the scope and methods employed are a little more difficult to ascertain.

4.3.2 Data Review and Comment

The area evaluations appear to be fairly detailed though given the densely vegetated surficial environment it is difficult from the available information to ascertain the accuracy or control points for these surveys.

The results of these surveys offer an excellent geologic picture of the various volcanic events of very recent origin. The documentation for these geologic maps was not available for review, but it is necessary, particularly for evaluation purposes, that a base map should be prepared which documents control points and features of interest that were used for developing the final maps. Also, given the densely vegetated surfaces of the survey areas, it would appear that many of the geologic boundaries presented might be inferred rather than observed. Therefore, the development of these geologic maps needs to be well documented as many future decisions and survey designs may depend on this data. This map should also be continually upgraded as additional data and information is gathered.

There does not appear to be any highly detailed prospect-oriented geological surveys performed beyond the area evaluations. These should be performed to locate potential exploratory drilling sites

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and to aid in the determination of the anticipated geologic conditions to be encountered at depth and to develop a model to serve as a guide for the planning and implementation of further exploration and development.

Admittedly, this is difficult due to the surface conditions, but it is necessary to the exploration program. One possibility for developing better detail would be to use shallow auger-holes to better determine the surface geologic formations.

4.4

Hydrologic or Hydrogeologic Surveys

Hydrologic surveys are required for any geothermal exploration since the knowledge of circulation or movement of fluids is essential in order to model any geothermal system. The understanding of cool and hot fluid movements both in the surface and at depth can be an aid in understanding other geophysical data as well as in determining the circulation of the reservoir and as an aid in building the geothermal reservoir model. The hydrologic reconnaissance should include temperature and discharge measurements of hot and cold springs, water table data and evaluation of surface and subsurface water movements. These surveys are typically general in scope and are of a reconnaissance nature. These surveys are minor in the total scope but as exploration continues, the data will also be employed on heat flow holes, test or exploratory wells, as well as for environmental and calibration purposes. Many of the surveys here will be part of or surveyed in conjunction with some of the geochemical surveys discussed in 4.5.

Regional geohydrology should include an inventory of springs, fumaroles, streams and wells in the area, and the measurement of physical and chemical characteristics of selected waters. It should result in preparation of a report and maps showing the patterns of circulation of surface water, and the inferred patterns, if possible, of underground waters; and the delineation of any special phenomena influenced by the geothermal system at depth.

The environmental hydrology will involve selection of a variety of springs, streams, wells and other water sources for periodic resurvey. Attention should be given to measurement of flow, temperature, and chemistry of these waters to establish a preprogram background data base that will be used to attempt to detect changes brought about by exploration and development of the geothermal resource. Climatological data on rainfall, run-off and temperature should also be collected to allow correlation of changes with climatic variations.

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4.4.1 Program Data

There did not appear to be any hydrological data available, except for some cursory data collected in conjunction with a geochemical survey performed in Kirishima.

4.4.2 Data Review and Comment

Since hydrological surveys usually involve only a small percentage of the exploration budget, it should be cost-effective to include this work in the budget.

4.5 Geochemical Surveys

Geochemical surveys primarily involve the sampling and analysis of waters and gases from hot springs, fumaroles, wells, etc. The study of the chemistry of these waters may determine their recent thermal environments, and the data obtained can be used to estimate anticipated temperatures at depth; discharge rate; phase of the reservoir (hot water, vapor or a combination of both) to estimate the chemical composition of the waters at depth; source of recharge; and other related information. These determinations depend on many inferences, assumptions and estimates as well as on scientific data. One of the most important assumptions of this analysis is that the waters are in chemical equilibrium with the reservoir and have moved rapidly to the surface. Unfortunately this may not be the case and must be given consideration in this analysis.

Chloride analysis can be used to determine whether a system may be hot water or vapor dominated. Chloride contents in excess of 50 ppm characterize most high temperature hot water systems and vapor-dominated systems generally display chloride contents of less than 20 ppm. Several constituents or ratios of constituents can be used to determine minimum reservoir temperatures of hot water geothermal systems. The solubility of silica in water is generally a function of temperature and the type of silica being dissolved. Silica solubility increases rapidly as temperatures exceed approximately 175°C but changes very slowly below 175°C. The ratio of molar concentration of Na, K and Ca are very useful as geothermometers especially as salinity and temperatures increase. Other useful measurements might include Cl/F ratios, Mg content, and Cl(HCO₃+CO₃) ratios. Deposits of sinter or travertine around extinct or non-extinct springs can help determine the thermal history and regime.

All chemical facts obtained are useful in the ultimate understanding of the geothermal system and reservoir, and these surveys should be initiated early in the exploration program.

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4.5.1 Program Data

From the available data it appears that geochemical surveys were somewhat neglected. In Hoho I and Hoho II there are no indications of any geochemical analyses. In Kirishima some of these geochemical surveys were performed on springs and fumaroles and the efforts should be commended.

4.5.2 Data Review and Comment

These surveys and resultant interpretative analysis are very important and should be considered an essential part of the exploration program. However, the types of analysis performed in Kirishima are difficult to ascertain. The Na-K-Ca method was utilized; but it is recommended that if other analyses and methods were not used, that they should be incorporated into the study. Also mixing models should be developed since it appears from knowledge of the areas under consideration that some mixing does occur.

4.6 Mercury (Hg) Soil and Soil-Air

The analysis of mercury in soil can sometimes be a rapid, cost effective reconnaissance tool in geothermal exploration. Hydrothermally active faults and fault intersections provide conduits for thermally driven mercury vapors to migrate to near surface depositional sites in the soil. Analyses of the soil and/or soil-air provides a basis for constructing a contoured map of the levels of mercury. Regions of anomolous mercury concentrations help to define potential "leaking" faults and fault intersections.

4.6.1 Program Data

The data provided by KEPCO indicates that these Hg soil and soil-air surveys were performed on an a limited but very detailed basis. In Kirishima this method was applied to the primary area of interest covering approximately 3,000 x 5,000 meters on a 100 meter x 200 meter grid system. This survey varies from a high of between 10 to 20 x 10⁻⁹ g/7 days to a low of near zero. In Hoho near Noya-Mizuwake another Hg soil and soil-air survey was carried out over an area of 1,600 x 3,000 meters and a second area of approximately 1,000 x 2,000 meters. The grid or detail of this survey could not be determined from the available information. This survey varies from a high of over 20 x 10⁻⁹ g/7 days down to near zero.

4.6.2 Data Review and Comment

From the available data it appears that the mercury soil and soil-air surveys received strong support for their implementation. The

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design of the survey and presentation of the data show considerable planning and detail, particularly for the larger scale Kirishima survey. However, interpretations and integration with other data should be made concerning structure, faulting, relationship of anomalies to surface thermal manifestations, etc. in addition to the presented contour maps. The mercury data were collected from both soil-air and soil but only the soil-air data was presented. The comparison of these two methods could be useful in establishing relationships for present day developing features and older established anomalies. The survey could possibly have been designed on a larger scale (area) and grid system (less detailed) initially, and then more detailed infill could have been undertaken in the more prospective areas, though the present grid in Kirishima does present a good amount of detail.

4.7 Gravity Surveys

A gravity survey should ideally begin with a regional map for the entire region of interest. Such a map is good for seeing the big picture of major structural detail and how the areas of interest fit into the total concept and also for determining the general regional gravity gradient to be used in the more detailed analysis. Sometimes this map can be blown up to provide the initial data basis for the area evaluation and in planning further gravity surveys if warranted. The gravity data should be acquired where access is fairly easy and surveying costs are minimized. This data when incorporated with other data can be used to design more detailed gravity surveys in prospective portions of the area.

Gravity surveys measure the density distribution of the subsurface. Variations in density can be caused by such features as intrusives, structural highs and lows, faulting, hydrothermally altered rocks—such as silica caps, stratigraphic changes and other factors.

4.7.1 Program Data

The gravity data presented for review are derived from a gravity survey of the whole region of central Kyushu, by the Japan Geothermal Energy Development Center.

4.7.2 Data Review and Comment

The evaluation of the available data is very difficult since there is no definition of detail or data control available for the maps presented. The way the data is presented, the contour interval, the shape of contours and details of features would indicate these surveys to be possibly semi-detailed reconnaissance area surveys. This semi-detailed type of survey would offer some latitude in the

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interpretation, or drawing and placement of contours and therefore has a marked impact on the resultant residual Bouguer gravity map.

Ideally, this acquired data should be recontoured on the basis of the additional knowledge or insight that the exploration program might provide into the structure of the area. This recontouring would honor all data control points but in areas of no control or between control points could exercise interpretative style in producing the final map. This recontouring would also greatly affect the residual Bouguer maps and may even affect the major directional trends and fault locations delineated. Also due to lack of knowledge of control locations many areas of broad evenly spaced contours may in reality have much sharper contours indicating faulting and show a broad open area for the remainder of the interval. This lack of control also impedes the accuracy and usefulness of two dimensional models.

The gravity data also needs to be interpreted. The available data is presented as only a map of the basic data with no analysis presented for fault locations or other features. Also if such interpretation was performed no two-dimensional model studies were made available. These studies could be very useful in interpreting the gravity data. Density data could have been obtained from the wells drilled in the various areas to be used in building these models. Electrical data delineating depths to various subsurface units and lateral stratigraphic changes could also be used to refine these models. Also additional data should be acquired at least in the prospect areas and over interesting features to improve the interpretation and models to better delineate the subsurface configuration.

4.8

Seismic Surveys

Passive seismic monitoring and mapping of local microearthquakes can be helpful in developing faults which are used in the reservoir model development. Microearthquake systems of varying activity have been observed at many proven geothermal areas as might be expected due to the tectonic settings of these areas. In addition, many geothermal reservoirs are characterized by a relatively high level of seismic noise. Accurate delineation of microearthquake systems and seismic noise sources may aid in locating fractured and permeable zones related to the geothermal system.

In microearthquake surveys an area of geothermal potential is blanketed with independent seismic stations at a nominal station spacing of 4-6 km. These stations, recording the ground motion at displacement gains of $1-3 \times 10^6$ at 20 Hz, will record the distinctive seis-

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mic arrivals of earthquakes down to Richter magnitude zero or below. Timing resolution between stations is held to less than a few milliseconds and time differences of the arrivals for any pair of stations is determined.

In order to locate an event a velocity distribution must be either assumed or determined. Inaccuracy of the velocity model causes an accuracy problem in the computed locations. Also the picking of the onset is somewhat subjective at the ± 5 ms level no matter what the playback speed. This type of error causes the locations to lose precision.

For an event recorded on eight or more stations with a nominal station spacing of 5 km and minimum timing and velocity errors, the location should be good to within $\pm 1/2$ km in plan and ± 1 km in depth. Errors in the computed location will increase outside the network of stations.

For a microseismic noise survey a model of a bubbling, gurgling, active, geothermal system is necessary. If several hours of ground motion data are recorded, preferably in the middle of the night to avoid cultural contamination, the following analysis can indicate the location of sources of seismic emission. Specimens of the data (perhaps 20-50 seconds long) from any two stations are taken and the two sets cross-correlated. The similarity of the two specimens as a function of the time shift between them is calculated. A peak in the similarity indicates the time shift at which the two signals most resemble each other. This time shift is exactly the information to serve as input to an event location program such as is used to locate microearthquakes. If the time shifts between each pair of stations is found, the location of the source of the noise in space is determined by the same method used for microearthquakes. The above described process is repeated over and over again with different time samples in order to confirm that a system has been located. The location of each "event" along with some idea of its quality can then be plotted. If a large number of such "events" are identified in one area, then it can be inferred a geothermal system has been detected and delineated.

The seismic methods for geothermal exploration can be expensive, but it can also be of significant value in confirming other exploration results. Therefore if the area seems active or on trend with an active structure, a reconnaissance survey may be in order to confirm the existence of a useful seismicity rate. Upon confirmation of a useful rate or an interesting historical record, a full-scale survey of 8-10 stations for several days may be indicated. Such a phased procedure, where time allows, may save a great deal of expense.

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4.8.1 Program Data

The available data indicates that microearthquake studies were only conducted in the Kirishima area. The map of distribution of microearthquake epicenters is interesting and indicated several areas of anomalously high activity with focal depths of generally 1 to 3 km.

4.8.2 Data Review and Comment

No seismic noise studies were made in any of the areas of interest.

Without knowing the seismometer locations, the overall quality and reliability of the results is difficult to ascertain, though from the microearthquake distribution map, it appears that seismometer locations may play a strong role in the conformation of the final map. More monitoring stations would probably be needed within and to the west of the area of prime interest. It might also be interesting to note the magnitude of these microearthquakes. The lower the magnitude, the recording of the events at only a few stations, and the higher levels of seismic noise often associated with these areas sometimes make delineation of depths of focus (hypocenter) and epicenter locations difficult to determine.

4.9 Radiometric Survey

Generally radioactivity or gamma ray surveys are initiated to measure the levels of naturally occurring gamma rays as an aid in the search for radioactive materials. A scintillation counter generally measure all gamma radiation in the energy range from about 50 keV to high energy cosmic events with an event detection efficiency greater than 90%. All igneous and sedimentary rocks contain varying amounts of three major and naturally occurring radioactive elements. All natural elements with atomic numbers greater than 83 (bismuth) are radioactive. In decaying, an atom may emit one or more gamma rays. Also the gas radon 222 is quite mobil as are uranium 234 and 226 which are quite soluble and may readily be moved through solution. Since 10 inches of rock will effectively mask all gamma raditions from sources beneath it might be expected that detection of deposits of high radioactivity would be difficult. However, under favorable circumstances, surface radioactivity might be related to concentrations at considerable depths. This could occur if some of the soluble isotopes have been taken into solution and moved to the surface possibly by means of underground water circulation along porous media with ultimate migration upwards along a major fracture or fault zone. Thus, delineation of fault or fracture zones that may be favorable to geothermal development might be located by this technique.

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4.9.1 Program Data

Surveys measuring the levels of gamma radiation using a scintillation counter were conducted only in the Kirishima area. An area reconnaissance evaluation survey was performed and in 1979 a more detailed survey was undertaken near exploratory well sites KT-4, KT-5, KT-6, and KT-7. In 1975 a survey was conducted along some of the roads in the area with a reading taken approximately every 150 meters. In 1979 a second survey was undertaken that was very detailed. This survey covers an area that is approximately 1,600 meters x 3,000 meters with measurements made on the intersections of a 100 meter x 200 meter grid.

4.9.2 Data Review and Comment

These surveys follow an ideal format. Initially there was a study done on a semi-detailed basis of the area of interest. This survey was then followed up by a more detailed survey over a prospect(s) that had shown some promise from this and other studies. The interpretation of this data and the assumed objective of these surveys were to locate zones of increased radioactivity that may be caused by soluble isotopes of U^{234} and R^{226} or by radon 222 gas that might bear a relationship to faulting and fracturing in the area. There is good distribution of data and zones of anomalously high concentrations are delineated.

In the interpretation of this data care must be exercised. The relationship of geology, erosion, stream or lake deposits and springs must be considered and weighed before attempting to correlate zones of anomalously high gamma ray data to faulting and fracturing. When some of these possibilities have been ruled out then this data should be combined and integrated with whatever other data might exist that could help determine fault locations.

4.10 Electrical Exploration - Self (SP) Potential

Self potential surveys have been utilized with some success primarily in the exploration for minerals. The principal mechanism for the self-potentials, such as those observed above certain sulfide ore bodies, are the result of differences in the oxidation potentials of the upper and the deeper levels of the subsurface, and concentrate preferentially into a good electronic conductor such as a sulphide ore body. These potentials are generally about 100 to a few hundred millivolts and are very stable in time. Some SP anomalies have been felt to possibly be related to electrolytic concentration potentials in the soils but these are generally 30 MV or lower and generally are time variant. Most anomalous conditions are

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generally felt more than likely to represent stable telluric conditions and as such are related to the subsurface.

Application of the SP method has also shown that it is possible to map fissures, cracks, shear zones and faults in the subsurface by means of this method. The use of SP in this area is based on the concepts or development of streaming potentials or the chemical zeta potential. This concept states that when water is forced through a capillary, a potential difference is developed between the ends of the capillary, the high pressure end becoming more negative. To state in a different manner, upward migrating water can produce a positive potential when a measurement is made near the top of the upwardly migrating portion of the system with respect to an arbitrary reference point. An extension of this concept to geothermal prospecting has been made where elevated SP values are present over the upward-migrating waters set in motion by convection currents emanating from the thermal energy source. A low SP value in relation to this may be the result of downward movement of water as they cool on the convection cycle.

In areas of undulating topography a correction may need to be considered before evaluating the data. Some experiments have indicated that certain soils and clays can develop potential differences of approximately 50 MV per meter head of water. This can be significant and must be carefully considered, with corrections estimated and applied to the observed self-potentials. Another correction to be considered is the telluric correction. If the mean strengths of telluric currents varies from day to day then the natural potential between two points on the ground will vary proportionately. Therefore, in accurate SP surveying all measured potentials must be referenced not only to a particular base point but also to a time base.

4.10.1 Program Data

The self potential method was applied on a very detailed basis in the Kirishima area. The data was acquired on a 100 meter x 200 meter grid over a zone of approximately 2,600 x 5,000 meters. The data ranges from a low of at least 300 MV to near 200 MV.

Self potential surveys were also performed in the Hohi I area. The data was acquired on an undetermined grid over a zone of 1,600 x 3,200 meters, with this survey located in and near the Otake and Hatchobaru geothermal fields. Data levels vary from slightly over 100 MV to slightly less than -150 MV.

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4.10.2 Data Review and Comment

The data made available appears to be very detailed in scope and exhibits many interesting variations. The documentation indicates a stable base station was chosen but no documentation was available to ascertain what corrections if any were applied to the data. It would appear that a time variant "telluric correction" and, in light of the marked terrain and hydrological features of the areas, some form of terrain or hydrological head correction may need to be applied or considered if they have not already been. It is also felt in view of the vegetation, soil conditions, moisture, etc. that some strong considerations must be given to electrolytic concentration potentials in the soils at the measuring site. Strong quality assurance is needed for the electrode implantation and use. The interpretation of the S. P. data should first consider relationship to geologic units or soils, vegetation, and hydrological features and concepts before progressing into a more detailed analysis. If the data is found to be mostly independent of these features then some inferences and correlation of the data to faults and fracturing and the geothermal system should be developed.

4.11 Electrical Exploration - D. C. Resistivity Methods (Schlumberger Arrays)

Direct current resistivity investigations have become one of the primary surface-based exploration techniques for the detection and delineation of geothermal reservoirs. These D. C. electrical exploration techniques measure the electrical conductivity of the sursurface at depth. Temperature, porosity, salinity of interstitial fluids, and/or content of clays and zeolites tend to increase electrical conductivity. These aspects of the subsurface tend to be higher within geothermal zones than in non-geothermal zones, and therefore, the electrical conductivity within geothermal reservoirs is generally relatively high.

The D. C. resistivity methods involve measuring the resistance of a generally non-homogeneous medium, the earth, to the flow of current applied to this medium at a specified distance from the measuring location. This is generally accomplished by use of two voltage, or measuring, electrodes and by two current, or input electrodes. The generally acknowledged electrode arrays in common practice today are the Schlumberger, Wenner, and dipole arrays.

These D. C. resistivity techniques are useful primarily because of their ability to locate zones of anomalously low resistivities.

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4.11.1 Program Data

The available data provided indicates that considerable D. C. resistivity data using the Schlumberger array has been acquired in the Kirishima area, in the Hohi I area, particularly over the Hatchobaru and Otake prospects, with a limited amount of data acquired in the Hohi II area of interest near Garan.

In Kirishima the survey generally covered a section of 4,000 x 8,000 meters with 200 meters between recording locations and 500 meters between traverses.

In Hohi I the data covered a section of approximately 2,000 x 5,000 meters with some longer reconnaissance control lines. The recording locations are 200 meters apart and there is approximately 300 to 500 meters between lines. In Hohi II 30 readings were taken in two intersecting 4,000 meter lines in the Garan prospect.

4.11.2 Data Review and Comment

As based on information derived from the paper "Evaluation of the Geothermal Potential of Kirishima by Resistivity Sounding Curves" (1979) by Gerland Buttacaroli and Seibe Onodera, depth penetrations were generally less than 1,000 meters with the conductive zone generally located within 100 to 200 meters of the surface. Information obtained from Wells KT-1, KT-2 and KT-3 should have been used to calibrate the resistivity data and to determine what this conductive feature is.

Also, in comparing the conductive feature to the geologic map there appeared to possibly be some correlation of the Byakushike pyroxene andersite lava flow to this resistivity anomaly. This should be studied further.

The general configuration of the Schlumberger array was with an AB/2 of 2,000 meters though some data was recorded with an AB/2 of 3,000 meters to obtain deeper penetration. The data were analyzed by the curve matching method for most of the surveys. In Garan it appears that an analytic solution was used to develop a model that could be compared favorably to the field data.

In Garan an AB/2 of 2,000 meters was generally utilized which gave an effective depth penetration of less than 1,000 meters and in most cases probably nearer 500 meters.

The electrical data made available appears to be reasonably detailed and provides good basic coverage to the prospects of interest. Unfortunately the data summary presented on the plates provided does

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not provide a useful means of reviewing the data. Resistivity data should normally be presented as a series of resistivity versus depth plan view maps and cross sections. The data as is best discernible generally illustrates a resistive-conductive, resistive-conductive-resistive or a resistive-less resistive section.

Once the relationship of the VES data has been correlated and calibrated by the well data for Kirishima, then additional electrical surveys can be designed based on these parameters. This may involve redesigning the Schlumberger surveys, such as increasing electrode spacings, or utilizing other electrical surveying techniques such as dipole-dipole or magnetotellurics. These surveys, when sufficient knowledge is gained, should be used to locate the drill sites. As direct subsurface information is gained from a well, these surveys should be calibrated and reevaluated before the next well is drilled.

4.12

Temperature and Thermal Gradient Surveys

Temperature, temperature gradient and heat flow surveys are utilized in a geothermal exploration program to help define zones where heat transfer may be most intense, and when mapped may give a qualitative analyses as to the location and shape of the hottest near surface heat accumulations. Measured values in excess of "normal" may be due to such processes as exothermic chemical reactions, high content of radioactive materials, friction along faults, intrusives and migration of waters of different origins within areas of normal heat content. Several types of surveys are available ranging from a shallow temperature survey conducted at 1 or 2 meters to intermediate surveys conducted at 100 to 200 meters, deeper surveys at depths of approximately 500 meters and measurements made from full depth exploratory or test wells which may be 1,500 to 3,000 meters in depth.

Temperature gradient measurements can be influenced by many factors other than a subsurface heat source. Movements of ground water can have particularly strong influences on the measured data. Even a relatively slow movement of ground water across a thermal anomaly can carry away the conductive and convective heat, and thereby displacing temperature distributions in the subsurface and grossly distorting gradient measurements.

4.10.1

Program Data

In Kirishima a survey of subsurface temperatures was made at 20, 25 and 30 meter depths. The available data provided only depicts the contoured map of temperatures at the 30 meter depth.

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In Hohi II a ground temperature survey at a depth of 20 meters was performed with the data presented but there is no indication of the survey density.

4.12.2 Data Review and Comment

In a shallow temperature survey such as in Hohi much care must be exercised in the design and implementation of the surveys. Consideration must be given to the effects of soil diffusivities, topography, vegetation, precipitation and movement of surface and ground water in both the design and interpretation of these surveys. Care must also be exercised in the acquisition of the temperature data in terms of borehole equilibrium and in preventing convection cells from developing in the temperature holes. These were given due consideration in this survey and the holes and the probes were cemented so as to prevent well bore convection.

This shallow survey appears to have delineated a limited thermal anomaly near the Shiratori hot springs and fumaroles. The anomaly may represent a source-reservoir feature beneath this area but most probably only represents a hydrothermally invaded zone near the surface that is related to the Shiratori surface thermal features.

Deeper drilling would be needed to determine if isothermal or reverse gradients would occur at shallow depths below 30 meters. The size of this survey and detail need to be increased. The data is presently on a 500 meter grid over a zone of about 3,000 x 4,000 meters. First the aerial extent of the survey must be increased so as to provide some comparison or control of the temperatures in nonprospective sectors to the prospective area. Data must then be acquired on an infill basis to extend or delineate features of interest. These features at this shallow a depth may only be 1 or 2 degrees Celsius so consideration of this must be evidenced in the presentation of this data.

Deeper thermal gradient holes would be useful but would probably not be cost-effective on a large scale but may be very useful to testing anomalous zones, such as resistivity anomalies, prior to more expense test and exploratory drilling.

4.13 Magnetic Surveys

Magnetic surveys are helpful, sometimes, in determining thickness of sedimentary cover and in the location of near surface intrusives and extrusive volcanic rocks. These surveys may also be useful in point determinations if temperatures are high enough. In some areas negative magnetic anomalies may be caused by hydrothermal conversion of magnetite to pyrite. Unfortunately, in most areas, so many

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factors influence the character of a magnetic survey that it is difficult at best to interpret and discern geological and geothermal significance to the data.

Aeromagnetic surveys are also useful and generally are more interpretable than ground magnetics. This data is less affected by high frequency near surface effects and resolution of depth to causative features is better. A curie point isotherm determination can also be estimated from this data. In calculating the curie point depth, it is assumed that the crust becomes nonmagnetic at the depth where the temperature reaches about 500°C, at shallower depths the crust retains its magnetism. The curie depth is then calculated by estimating the thickness of the magnetic crust. From this data a temperature gradient contour map can be constructed based on the curie point depth data. These data give a gradient averaged over a much greater temperature and depth range than temperature gradients collected from shallow drill holes where near surface aquifers can bias the results.

4.13.1 Program Data

Ground magnetic data were collected on an undeterminable spacing over a very limited portion of Hohi I in the Otake prospect. The data shows much variation with several anomalous zones delineated. Many of these features due to their high frequency are probably related to near surface phenomena such as flow boundaries, alteration zones, thicker soil cover and possibly some faulting and fracturing.

4.13.2 Data Review and Comment

A larger aerial extent is needed to give this survey some validity and also the interpretation of this data to be meaningful must show some correlation to other data collected.

Aeromagnetic data is generally more useful than ground data but the acquisition of this data may not be cost effective. The Curie point map would be useful but due to the recent volcanism and the many surface thermal manifestations may not be cost justifiable for an area such as Kyushu.

4.14 Exploratory Well Evaluations

The drilling of exploratory wells provide the only way to determine the actual, in situ, geothermal-reservoir characteristics and potential as well as a direct means of correlating the other exploratory data. Data acquired from these drill holes should include information on the temperature-depth distribution, lithology and strati-

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graphy, pressure-depth distribution, permeability and/or porosity, fluid composition and content, and other information useful to the exploration program.

These wells should also have a full set of logs performed on them. These logs should specifically include but are not limited to a caliper, temperature or differential temperature, compensated formation density, gamma ray neutron and possibly a pressure tool. The caliper log is run to determine hole diameter that will be used in determining tool size and calibration of surveys such as the density survey. The temperature survey to determine well temperature and possible hot or cold water entry points. The density log is a radioactive tool that can provide lithologic information but is primarily utilized for locating fractures. The gamma ray neutron survey can provide good lithologic evaluations and sometimes formation fluid entry points. A pressure survey spinner tool is also sometimes useful for quantitative analysis for determining entry flow from fractures though this tool is still being perfected. Industrial electric tools are also very useful in a fluid filled well. These are useful in determining lithology and stratigraphy as well as in calibrating surface electrical exploration. These tools and particularly the support cables and electronics have been perfected in the past 2 years. Such that they can be reasonably accurate up to temperatures of 530°F to 600°F.

All of these surveys are useful but without a skilled experienced interpreter they may not be cost effective. Only an expert log analyst can understand the subtleties of these logs and properly integrate the information to produce the optimal results.

Production flow and reservoir (interference) testing must also be performed on these wells. All of this information will be utilized in determining the geothermal potential of the prospect, in developing a reservoir model(s), in determining the economic potential of the reservoir, and in calibrating, refining, and reevaluating geophysical and other surface exploration methods, data and interpretations. Data should be acquired so that wells are located on the most prospective features and therefore are assured the best possible chance to adequately test both the surface geophysics and other methods as well as the subsurface and the potential geothermal reservoir. As wells are successively, not simultaneously, drilled additional exploration may be required to better locate the next well. At least three successful wells are felt to be needed to confirm a prospect or reservoir.

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4.14.1 Program Data

None of the data bases appear to be sufficient enough to justify the location of any deep exploration wells.

Logs of temperature, lithology, and drilling occurrences were made available for review.

4.14.2 Data Review and Comment

The wells that have already been drilled in Kirishima or are drilling are not assured the best possible chance of success. Additional data may have indicated that wells KT-1, KT-2 and KT-3 were not drilled to a deep enough depth and/or that they may have been located over only a minor near surface feature with no prospective geothermal reservoir sufficient for electric power generation present. The cost of this additional exploration would have been only a small percentage of the total cost of these three wells.

The four additional test wells in Kirishima are based on a wide variety of data, but the data are not sufficient. The analysis of wells KT-1, KT-2 and KT-3 indicates that the potential reservoir may be deeper than 1,500 meters, yet the data available project no information to such target depths. Therefore additional exploration should have been performed here also to provide deeper data, to better locate these wells, and also for developing a better understanding of the well information and how this information relates to the subsurface away from the well bore.

The exploratory wells in the Hohi I area do not appear to be based on exploration data and as such may not be testing the subsurface in the best possible locations and evaluation of the information from these wells will be difficult without a comprehensive surface exploration program.

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5.0

EXPLORATION STATUS

This report section emphasizes the overall progress of geothermal resource development as viewed by Rogers Engineering and its consultants based on the data available. A review of certain overall aspects and comments are included as well as subjective evaluation of the status.

5.1

Sequential Exploration Focus

The five resource exploration steps of the Standard Program are reviewed and commented on in this section as they relate to KEPCO's program. These steps are defined in Section 1.2 and result in the many methods and surveys with a focus on more clearly selecting the better locations. Each step requires the integration of data from all previous steps for the location in developing the focus. This integration is a continual process each time more data is obtained.

5.1.1

Regional Evaluation

Regional studies and evaluations are fundamentally integral to the entire exploration program. No thorough evaluation or assessment of the selected areas or prospects can be complete without knowledge of how these pieces fit into the regional framework. In reviewing the available regional data it appeared that no extensive cohesive regional study was undertaken, though it appears that several evaluations of the geothermal potential of Japan have been initiated over the past 30 years.

In reviewing those reports that have been translated into English it appears that there is a general lack of sufficient documentation with no cohesive data base established. In a regional evaluation, all prior reports need to be considered. A regional analysis is needed to provide the quality and reliability sufficient for KEPCO to base and formulate sound decisions on.

The regional report should be a summary of the findings discussing the regional evaluations and tectonic framework, outlining the procedures for selection of the area(s) of interest if any exist and how these areas fit into the regional concepts and also discussing other information that may be useful to the exploration effort.

5.1.2

Area Evaluation

The area evaluation must be detailed enough to delineate prospects and reconnaissance enough to provide coverage for the entire area while still being cost effective and fiscally responsible. The area exploration must determine the relationship of the prospects to the

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area and regional framework. In reviewing the data available for each area several features are evident. The data for the Kirishima area is the most complete, while the data for the Hohi I area is less complete and the data for the Hohi II area is only marginal.

In Kirishima, many surveys were performed with some of them, such as the gamma ray surveys, following a well defined area to prospect or semi-detailed to detailed format. Other methods such as the mercury soil and soil-air survey were only utilized on a very detailed basis with no area-wide coverage. The area survey should have been performed initially and then more detailed surveys should be performed in the portions of the area survey that indicate prospectiveness.

5.1.3 Prospect Evaluation

The prospect evaluation should build on the regional and area evaluations and is very important for determining exploratory well locations, in understanding and delineating the reservoir, and in aiding in the development of a reservoir model(s). The prospects do not appear to be located by the regional area focus of geologic and geophysics studies. In reviewing the available data for each area it appears that the prospects in the Kirishima area have the most detail, with lesser detail in the Hohi I area and no detailed data available in the Hohi II area.

5.1.4 Exploration Results Report (Feasibility Study)

We did not see such reports or any indication reports have been prepared like the one suggested in Section 1.2.2. This report is the basis for either doing more surface exploration or drilling an exploratory well. It presents a preliminary model of the anticipated reservoir which the exploratory wells are to confirm. It appears exploratory drilling proceeds without this type report.

5.1.5 Exploratory Well Drilling

The past exploratory well drilling programs have included wells about 1,500 m deep and a bottom hole diameter of 65 mm. This appears to be a standard; however, exploratory wells of this depth and greater should be capable of reservoir production testing and these wells are too small a diameter for such testing.

Exploration wells are drilled to depth using mud. The exploratory wells are taking too long a time to drill and are therefore very expensive. Larger more modern rigs with crews more conscious of geothermal drilling are suggested to reduce cost and time.

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One objective of exploration should be to reduce risk and cost in well drilling and to insure the best possible chance for success. This exploration tie did not appear at this drilling stage of the program. Therefore after several exploratory wells the subsurface may still not be adequately tested to confirm or negate prospect's geothermal potential. The exploratory well drilling program is not accomplishing its purpose.

Each well should provide information that can be used to calibrate the geophysics. Based on the well information some geophysical studies may need to be reinterpreted, additional methods utilized, or other surveys may need to be redesigned. This may result in relocating a previously permitted drill location. To follow this policy would seem to be better then to possibly drill a \$1,800,000 (400,000,000 yen), 3,000 meter well that is not in the optimal location to adequately test the subsurface and locate the reservoir.

No reports were presented or data from them to indicate the existence of reports like those of the Standard Program, Section 1.2.3.

5.1.6 Well and Reservoir Testing

At the time of our review, there were no exploratory well successes in the exploration areas of Hohi I, Hohi II and Kirishima. Existing reports in the Hohi I area covering Otake and Hatchobaru production areas were not reviewed. From our understanding of the previous developments reservoir modeling, conformation and remodeling is not a part of the exploration or development program. Well testing is a method which should be used to evaluate a reservoir along with the other data and techniques. Well testing has been accomplished in the existing production areas but not with the resource model in mind.

5.1.7 Exploration Summary Reports

This Standard Program step has not been done for the new developments in Hohi I, Hohi II and Kirishima because the resource exploration has not progressed this far in its successful completion. Refer to this report Section 1.2.5 for details which should be in such a report.

5.2 Kyushu Island

This section presents our review and comment on the report submitted as data in Section 2.1. This report very generally presented a geothermal potential evaluation of Kyushu Island. It did not include the physical data anticipated in such an evaluation. The

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megawatt potential could be very misleading because of the derivation of the totals.

It is a recognized fact that there are many ways to make evaluations and create definitions of words. The first point to make is the terminologies of region and area used in the report do not agree with those of the Standard Program presented. They also do not agree in terms of areas covered. The only similarity is that the Standard Program area is the same size as the area of the region in the report. The Standard Program area and prospect evaluations are apparently not done but surveys are done on report area of 2 KM² about one-fifth the size of a suggested standard prospect. It is suggested that the focus from region in the report (area) to area in the report (one-fifth the size of a prospect) is too quick a focus. It leaves out many important features.

The next recognition is the megawatt potential of an area by the exploration wells or data. An area, 2 KM² block, should not be given a 50 MW potential unless it has a successful, producing geothermal well of the proper temperature.

The 2 KM² areas which we understand are attractive 50 MW power plant sites have no geological or geophysical connection to potential reservoirs. They appear to be reservoir independent. The land ownership analysis looks good and reasonable presenting the potential availability of lands outside parks and regulated forests.

In such an overall evaluation the whole island should be addressed pointing out the Standard Program areas of interest created by surface manifestations; hot springs, fumaroles, etc. and surface geology. The surface interests should be tabulated by temperature and chemical composition. Prospects should be defined by geographical areas large enough to encompass the attractive surface features. Geothermal wells should only be counted if completed into a reservoir of sufficiently high temperature.

The report is a good start on the reconnaissance but we feel is short of being able to define potential for the Kyushu Island. A potential for the island should be developed based upon specific data indicative of potential reservoirs.

5.3

Hohi I Area

In the Hohi I area most of the surveys were too detailed in design and limited in areal extent. They did not totally fulfill the needs of an area survey, in terms of evaluating the area and in determining the relationship of the prospects or detailed surveys into the area and regional framework. Additional prospect or detailed sur-

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veys are also needed to further delineate the interesting features that have been located by the present data base.

The exploratory wells in the Hohi I area do not appear to be based on exploration data and as such may not be testing the subsurface in the best possible locations and evaluation of the information from these wells will be difficult without a comprehensive surface exploration program. There is no explanation of the well drilling sequence suggested by the future exploratory well numbering system.

The budget presented for future exploration appears excessive related to the Standard Program. It should not take 12 exploratory wells and \$26,300,000 to do future exploration for another power plant. The present data does not indicate a well should be drilled in each report area (numbered 2 KM² blocks) nor does it indicate a 50 MW plant may be able to be located there due to an independent reservoir source. The Standard Program would suggest that for each new independent reservoir and the first 50 MW plant on that reservoir would take \$9,300,000 (2,000 million yen) for the resource exploration step. Additional power plants on the same resource should require much less expense.

The Hatchobaru and Okate reservoir models need to be developed and then an exploration program for additional plants would follow based upon a good understanding of the existing reservoir features.

The reservoir developers criteria for others is considered to be too restrictive. It should be the same as the standard program, and the final exploration summary report and all supporting data would be submitted to KEPCO at the time of steam supply contract negotiations. The negotiations can only occur after the reservoir is developed through the resource evaluation step of the overall geothermal development program.

5.4

Hohi II Area

In the Hohi II area (Garan) there is very little data available and any evaluation is most difficult. In all the areas, and especially the Hohi II area, additional area evaluations are warranted. The major drawback is not the types of surveys performed, but instead is rather the lack of design of these surveys for evaluating the area and the apparent lack of integration between methods to plan additional work or design other surveys.

In the Hohi II area considerable area data needs to be acquired and then detailed prospect evaluations and surveys should be made based on the area data base. This all needs to be performed before loca-

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tion of any exploratory wells can be economically accomplished. There is only very limited data, but four wells are going to be drilled very soon. Some of these wells are not even on the basis of any geophysical data nor on a prospective anomalous feature. More explorations need to be done here before these wells were located or drilled.

5.5

Kirishima Area

The Kirishima surveys are good but additional data would seem warranted before any drill locations are established. The additional data primarily needs to reflect deeper, 1 to 3 Km, aspects of the subsurface. This additional data, particularly electrical such as magnetotellurics, is needed to locate and/or better delineate the prospective reservoir(s).

At present in Kirishima and in past programs the exploratory wells are drilled at the same time. This practice leads to obtaining less information, requiring more supervision and management activities and is more costly.

In the exploratory drilling program, it is felt that sufficient exploration has not been undertaken to justify drilling of any wells. If more exploration had been initiated then possibly it would have been realized that KT-1, KT-2 and KT-3 would not have penetrated the geothermal reservoir unless they were drilled deeper than 1,500 meters or that no geothermal reservoir was present. Compared to the drilling costs of approximately \$3,600,000 (792×10^6 ¥) for these three wells it seems that a considerable amount of exploration in excess of the present program could have been done.

The four additional test well locations in Kirishima are based on a wide variety of data but if the reservoir is felt to be below 1,500 meters as was indicated from analysis of KT-1 thru KT-3 then the available data that these wells may be located on is not reflective of the potential target depths. Therefore additional exploration should have been performed to provide deeper data, to better locate these wells, and also for developing a better understanding of the well information and how this information relates to the subsurface away from the well bore.

It also seems that it is encompassing a very high risk to be drilling four additional exploratory wells, KT-4 thru KT-7, in this area with no more data than was available for KT-1, KT-2 or KT-3. More electrical exploration such as dipole-dipole, larger spacing Schlumberger arrays, and/or magnetotellurics should be undertaken. It also does not appear prudent to drill four wells simultaneously

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that are within 600 to 1,200 meters of each other and are within an area of 1.5 km². Even if these wells are felt to be testing different reservoirs it seems that more benefit could be gained from drilling these wells in series with each additional well location and drilling parameters based on information gained from the preceding well.

The future exploration budget in light of the past exploration results appears to be very large. No amount was available for previous exploration costs; however, in addition to surveys three unsuccessful exploratory wells have been drilled and an additional four exploratory wells are being drilled presently. The results of the present four wells are unknown at this time. The future exploration expects to spend \$9,900,000 (2,100 million yen) more than already has been expended by more surveys and five more wells. The Standard Program indicates only a total of \$9,300,000 (2,000 million yen) should be spent on the development of a new reservoir. Sufficient results are not being accomplished for the monies being spent according to the Standard Program criteria.

The five new well locations do not appear to be based upon exploration data or the current wells being drilled. No further drilling should occur until all previous work has been integrated to justify proceeding. Because of the lack of regional and area analysis there is less than normal expected success of the Kirishima area.

5.6

Area Comparison

The Hohi I, Hohi II and Kirishima KEPCO areas are the only areas of the original five on which we have any data to make evaluations. With regard to new power plants, no area has progressed to the point of considering more electric power production. The exploration in each of the above three areas has not yet progressed, in our opinion, to even drilling exploratory wells based upon exploration data per the Standard Program Section 1.2.

It appears there is an overriding considerations in current geothermal development philosophy in Japan which tend to subordinate the methodical scientific approach. In the current competitive, claim-establishment framework it may be necessary to forego the logical, step-by-step approach of an integrated exploration program and just take the risk of drilling wells in hopes of hitting the reservoir. The consequences of this decision must be recognized and admitted and are certainly reflected in the final costs.

It is evident from the foregoing that the exploration work has not yet advanced to a stage where logical reservoir models have been developed integrating the various exploratory efforts, which could

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form the basis for a competent evaluation of the geothermal potential of the three active areas. For this reason it is not yet possible to make a comparison of the areas on the basis of geothermal reservoir potential. Accordingly, comparison of the areas can only be made at this time on the basis of the exploratory efforts already made.

5.6.1 Regional

The initial comparison of these areas should be in terms of their regional relationship. It is useful to know how these areas fit into the regional tectonic and geologic framework and how they were selected from the regional analyses. The selection of these areas and the interrelationships of these areas is not evident due to the lack of a sufficient regional data base and analysis.

5.6.2 Hoho I Area

This area enjoys the advantage of producing geothermal wells that support two electric power plants. However, it is not apparent that the reservoirs furnishing energy to these two plants have been adequately delineated or adequately tested and appraised. Therefore there is no reliable estimate that there is sufficient resource in these reservoirs to support the minimum required economic life of the power plants.

The exploration of the area is incomplete, but work already done is a good base. It needs to be integrated and expanded to produce well documented models of the producing reservoirs, plus additional work patterned after the Standard Program to identify other reservoirs.

5.6.3 Hoho and Kirishima Areas

The lack of a fully developed exploration program that has sufficiently sampled the subsurface for these areas of interest and postulated prospects also impedes the comparison process. It may be inferred from the analysis that the local geological and structural configurations of the three areas may be very different. Unfortunately the available data is not sufficient to fully develop and support these judgments.

It does appear though that the Hoho I and Hoho II areas with "basement" rocks of hornblende and andesites may be geologically and tectonically different from the Kirishima area where "basement" rocks are principally composed of pyroxene andesites. In Kirishima the reservoir is believed to be within fractured "basement" rocks, while in Hoho I (Hatchobaru) the reservoir is at the fractured

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"basement" porous tuffs and breccia interface. In Hohi II (Garan) the anticipated reservoir was not fully understood or discussed.

Due to the depths of the Hatchobaru, 750 to 1,250 meters, and the Otake, 350 to 600 meters, reservoirs it was felt by KEPCO that Schlumberger D. C. resistivity aided in locating and delineating these reservoirs. In Hohi II insufficient data exists to adequately evaluate the perspective reservoir but there are some interesting conductive features that may be reservoir related and warrant further investigation. In Kirishima the depths to the prospective reservoir may be too deep to be located by these D. C. resistivity techniques. The data available is not sufficient to make an adequate or in-depth comparison based on this method. Without additional subsurface knowledge and calibration to the existing wells comparisons of the various data bases and exploratory techniques is very difficult at this time.

In Hohi II no sufficient data base exists to make any further analyses or comparisons to the other area.

In Kirishima insufficient information is available at the anticipated prospective depth to develop any further comparisons to Hohi I.

5.7 Data Missing

Section 2 presents the data which was available for us to work with to make the analysis and report. The following section lists the reports which were not available for analysis but which should be a part of a complete exploration program.

5.7.1 Regional reports

5.7.2 Reports on each individual survey method used including the interpretative analysis of this data.

5.7.3 Base raw and processed data for each survey.

5.7.4 Reports discussing the integrated interpretations and analysis of these data synthesized into reservoir "models".

5.8 Section Summary

It is apparent that many of the phases of the Standard Program for resource exploration presented in Section 1.2 have been overlooked. There are many inadequacies in the current exploration program of KEPCO when it is compared to the Standard Program. A recommended

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approach is suggested in Section 6.6 under the title of priority recommendations.

In terms of the Standard Program in general, no area is ready yet to be drilling exploratory wells. The indicated exploratory well locations are not substantiated by potential reservoir models. The future exploration budgets appear very high for the anticipated electrical output achievable.

It does not appear that sufficient new reservoirs can be developed prudently to achieve the 200 MW additional electrical output with the existing approach and program. The Standard Program should be considered in more detail to achieve better performance from the resource exploration.

Intuitive judgment suggests that there exists great geothermal development potential on Kyushu Island. The present program, however, does not utilize the most effective approach to the exploitation of the potential.

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6.0

RECOMMENDATIONS

The recommendations are based on the presentations of data received, survey and method evaluations, and an evaluation of the status or progress of the geothermal exploration in Hoho I, Hoho II and Kirishima. These recommendations are aspects which it is felt should be addressed in view of all the various conditions to improve the current exploration efforts by KEPCO. The actual effort involved to carry out the recommendations is considerable; however, in our opinion are justifiable and cost effective to implement.

6.1

Legal Status

Procedures, policies, definitions, and laws relating to the geothermal resource must be established. In particular these concepts need to be developed in the area of ownership of the geothermal resource. At present there are too many ambiguities in defining this resource and there are no clear government policies established to give the geothermal development program the impetus and direction that it needs. It appears that until this occurs there will be inefficiency, unnecessary excessive expenditures, high risk, many difficulties in establishing ownership rights which can have poor or even detrimental affect on development of the geothermal reservoir so that the full potential of the reservoir may never be realized or utilized.

These obstacles have apparently impeded KEPCO's efforts to develop a fundamentally sound, cost effective and cohesive exploration policy. Establishment of clear procedures, policies, definitions and laws relating to the geothermal resource must be given a high national priority.

6.2

Exploration Focus

The geothermal development program must establish an exploration focus similar to the Standard Program Section 1.2 in order to achieve better results from exploration efforts and financial resources.

6.2.1

Regional

More effort is needed in regional evaluations and in establishing the preliminary data base. No regional evaluation was presented to justify why exploration was being considered or is going on in any area. If no such evaluation is made there is no rationale as to why an area may prove good or bad under further detailed exploration.

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6.2.2 Area

The area exploration efforts were generally too limited in design, areal extent, and did not meet the objective of fully exploring the area of interest and in establishing the data base and exploration framework to subsequently evaluate potential prospects delineated within the area.

6.2.3 Prospect

In the prospect exploration stage greater detail is needed over the prospects and additional detail was needed over features found to be of interest. This portion of the program seemed to be too cognizant of the intuitively designed 2 km² prospects such that many of the exploration surveys were designed around them instead of being designed to locate and delineate the potential reservoir(s).

6.2.4 Central Library Control, Data Processing System

It appears that many individuals, disciplines and organizations have the necessary information, documents, data, etc. but that no individual or group has been given the responsibility for collecting, coordinating, cataloging and disseminating this information. A Project Library organization should be established to perform these functions as well as being responsible for having general knowledge of the content of these reports, etc. It should also be charged with updating and upgrading this data base by contacts with universities and other organizations that may have information useful to the effort.

This library should probably also contain the job files. These files are very important from a development, managerial, quality assurance and historical perspective. They should contain information relating to the functioning of the job, such as contractor evaluation reports, operations reports, quality assurance reports; memos, phone conversational writeups, contracts; weekly, daily, etc., field reports; authorization for expenditure requests and approval, contractor bids, etc.

Considering the potential scope of KEPCO's geothermal program, these data functions should be augmented with an electronic data processing system.

6.3 Exploratory Well Drilling

Recommendations concerning the current KEPCO exploration drilling programs are made. These reflect the present divergence from the Standard Program.

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Exploratory wells within a given prospect (1,000 - 3,000 hectares) should be drilled sequentially, one at a time, having time to evaluate and correlate the findings of the first well before starting the second well.

Implementing the purpose of substantiating the exploration surveys by exploratory drilling requires a combination of sampling drilling cuttings and coring on each well drilled. The method requires continuous cuttings analysis and coring only when the cuttings indicate a change in lithology. In our opinion no well should be cored the entire depth.

The method of drilling is also important. Mud drilling is fine in zones where geothermal production is not expected. However, other methods air, water, or foam must be used in potential production zones so as not to seal off the zone by the drilling mud.

The drill site locations should be substantiated with more exploration justification prior to drilling.

6.4

Reservoir Modeling

There are three stages of reservoir modeling which the current exploration program appears to neglect. The first model of the potential geothermal reservoir is developed from the exploration surveys and findings prior to exploration well drilling. The purpose of the exploration well drilling is to confirm or modify the initial model until a sufficient model, second model, is proven with drilling and well testing to substantiate a productive reservoir. The third model of the reservoir is a continuous modeling and testing of the production wells after the power plant is operating. Not one of these models is adequate to do the whole job but rather it is a continuous effort and approximation to prove long term producibility and capacity of the reservoir.

6.4.1 It is recommended that in the power plant producing areas, Hoho I, a model be developed to explain the characteristics observed, extent and capacity of the reservoirs. This is most important because of the substantial monies invested in power plants and wells.

6.4.2 It is recommended in areas where exploratory drilling is under way now to take all available data and create a model. Additional drilling locations should not be implemented without the potential reservoir model.

6.5.3 It is recommended in areas where no exploratory wells are currently being drilled that no drilling start until the exploration data develops a model and confirms the drill site location.

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The process of developing a potential reservoir model by exploration methods and then refining it by each successive step along the long sequential path of development into production is the only way to achieve a high degree of success with exploratory or production wells. Exploratory well drilling should produce three fully productive wells for every five drilled. Otherwise most likely the area is not a sufficiently attractive one in which to spend more time and money.

6.5 Survey and Methods

This section of the report presents a summary of recommendations applicable to the surveys and methods utilized by KEPCO. These comments are presented not as recommendations to do all these surveys as future exploration, but instead are presented to provide guidelines for improvements if these surveys in Section 4 are utilized in further exploration efforts.

The following recommendations are made for improvement of the general exploration program if such studies are used in the future:

6.5.1 Satellite Imagery and Aerial Photography:

- a. Expand the use of satellite imagery to its full potential as described in Section 4.2.
- b. If the quality of the 1:40,000 photography is sufficiently good, enlarge to 1:15,000 and re-study the photogeology plotting more detailed features. Surveys should be acquired at the 1:15000 more detailed size to allow plotting more detailed features.
- c. Mylar overlays should be made of the mosaics, plotting all interpretative data. Synthesize these photogeologic maps with the geologic maps derived from the literature and field surveys.

6.5.2 Geological:

- a. Refine the geologic maps by documenting the control points.
- b. Develop detailed geologic maps of the prospect areas. Use shallow auger holes to determine surface geology where surface conditions limit normal observations.
- c. Synthesize geologic information with other data in to reservoir models.

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6.5.3 Hydrogeologic Survey:

Since no detailed hydrogeologic studies have been made in the areas, a program should be initiated, consisting first of a semi-detailed study of the entire area. Then, after a synthesis of all area surveys has been made and prospect areas defined, detailed surveys should be made of the prospects.

6.5.4 Geochemical Survey, Hot Water and Gas:

In areas where no geochemical studies of geothermal water and gases have been made it is highly essential that a program be initiated as soon as possible. First, a semi-detailed study of the whole area, and later, detailed studies of the prospects. The scope of geochemical studies must be expanded to include other observations as described in Section 4.5.

6.5.5 Geochemical Survey, Hg Soil and Soil-Air:

- a. Correlate the data with structural geology.
- b. Compare soil data with soil-air data and interpret results.
- c. Acquire semi-detailed and in-fill data where needed.

6.5.6 Gravity:

The existing gravity data base should be augmented as follows:

- a. Obtain control points for the present survey and then obtain additional observations to add more detail in the prospects and over interesting features.
- b. Perform analysis and interpretation relative to faults and other features.
- c. Correlate data with density information from wells, and with electrical and geologic information to develop models, structural cross sections and structure maps.

6.5.7 Micro-seismic:

- a. Initiate microearthquake study program for the whole area on semi-detail spacing.
- b. Initiate microseismic noise survey of prospects.

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- c. Study prospects, on detailed basis.
- d. Correlate results and synthesize with other data in reservoir models.

6.5.8 Radiometric:

- a. Initiate a gamma radiation survey program of similar scope and design to that already done in the Kirishima area.
- b. The results obtained should be carefully analyzed and correlated with other surveys.

6.5.9 Electrical, Self-Potential (SP)

- a. Initiate SP surveys in the area and prospects not covered.
- b. Conduct a quality assurance review of the earlier work.
- c. Correlate results with structural data and with surface geothermal manifestations.

6.5.10 Electrical - D. C. Resistivity Methods:

- a. Redesign electrode arrays and initiate Schlumberger or other D. C. resistivity surveys in those areas that have not yet been covered or do not have data from depth reflecture of the anticipated production.
- b. Present data in resistivity vs depth plan view and cross-section maps for more effective interpretation.
- c. Correlate this information with electrical and other exploratory data from exploratory wells which may have been drilled.
- d. Correlate results with other data in process of developing reservoir models.

6.5.11 Thermal Gradient Survey:

- a. Initiate full program in areas not covered, with shallow (___ m) holes for a semi-detail coverage of the whole area, followed by deeper (_____ m) holes in the prospect areas and anomalies.
- b. Increase the aerial extent of the thermal surveys to extend beyond the prospect boundaries of control and in areas not yet covered.

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- c. Drill deeper (_____ m) heat flow holes to test anomalies of resistivity and temperature prior to drilling large exploratory wells.

6.5.12 Magnetic

- a. Obtain magnetic data observations only along with the additional gravity readings that are taken.
- b. Correlate results with other surveys.

6.5.13 Exploratory Drilling (Large Holes):

- a. Large diameter, expensive exploratory wells should be drilled sequentially in an area, not simultaneously, so that inferred subsurface models can be refined by each successive acquisition of real data.
- b. A full array of geophysical logs should be recorded in each exploratory well.
- c. Planning for additional exploratory wells should be revamped so that expensive exploratory wells are not drilled until a rational program of exploration has been completed and has optimized the chances for penetrating commercially productive geothermal reservoirs.
- d. Delays caused by such rescheduling of drilling activities could be utilized by refitting drilling forces with adequate sized equipment tailored to the special requirements of the conditions in Kyushu.

6.5.14 Additional Survey Recommended

Magnetotelluric Surveys

Magnetotelluric surveys are a sub-classification of electrical exploration methods. The results derived and the application of this method to geothermal exploration depend upon the electrical properties and the subsurface. This method relies on natural fluctuations in the earth's magnetic field which induce electric currents in the conducting earth, which in turn generate a secondary magnetic field. The magnetotelluric (MT) method measures the tensor components of these naturally occurring electric and magnetic fields at the earth's surface. The basic field setup and measurement usually consists of two horizontal orthogonal components of the telluric (electric) field. This is generally accomplished by measure of each electrode pair the potential difference between the two

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electrodes and dividing by the distance between them. The three components of the magnetic field can be detected by either induction coil sensors or "squid" magnetometers.

A magnetotelluric survey was not performed as a part of KEPCO's present exploration endeavors but since electrical methods are of prime importance to locating geothermal resources this method may be of importance to future or further exploration efforts and is therefore included in this report. Due to the costs involved with this method it is generally advisable initially to utilize other electrical methods and such other methods necessary for a well founded exploration program to aid in the decision to use this method and in the planning and design of this survey.

Magnetotellurics is a natural source, site specific, electrical exploration method that records information in time relating to the subsurface beneath the measuring site. This data, depending on near surface resistivities, is generally recorded from approximately 300 meters (1,000 feet) to 10 kilometers (30,000 feet) or greater, if desired, beneath the surface. The usefulness of this method is the ability to record electrical data from near the surface to great depth. The data therefore can detect conductive zones that may be related to geothermal reservoir features at realistic depths. This data can also aid in detection of major faults and in locating conductive anomalies that may be associated with magmatic intrusions in the crust. This data can therefore be very useful in both delineating very shallow (< 1 KM) and deeper (1 to 3 KM) or underlying reservoir features and in locating source features such as shallow magma bodies and deeper crustal upwarps.

6.6 Priority Recommendations

This section presents a brief summary of the recommendations for future exploration endeavors by area. These recommendations within an area are presented in their order of importance. It is felt that these recommendations are integral to establishing the resource exploration program on a firm base such that risks are reduced and the probability of success is greatly increased.

6.6.1 Kirishima

In the Kirishima survey area it is recommended that the present exploration data be correlated to the data from the KT-1, KT-2 and KT-3 wells already drilled and to the data from the KT-4 through KT-7 wells being drilled presently. Logs, surveys and measurements performed in these wells should be designed with consideration given to calibrating or assisting in the interpretation of the surface data. If a full suite of logs was not performed on a particular

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well then, if possible, the well should be reentered and these logs taken.

Deeper data must also be acquired. In particular it is recommended that longer electrode arrays be experimented with using the well data for quality assurance of results. If the longer arrays appear to be successful then those should be implemented over the area on a semi-detailed basis. In-fill should then be performed over prospective zones. Magnetotelluric's should also be utilized here with the layout and design based upon all the exploration data and particularly the D. C. resistivity surveys if they are reflective of the subsurface to sufficient depth.

After all this information is collected, calibrated, reinterpreted and refined then this data must be correlated and integrated to provide a sound interpretation of the area to develop the prefeasibility study discussed in Section 1.2.2.

6.6.2 Hohi I

In the Hohi I area, it is recommended that before additional exploration and drilling is performed that efforts should be expended to increase understanding of the Hatchobaru and Otake geothermal reservoir systems. Particularly efforts must be made to develop a reservoir model for these systems. This knowledge will be very useful in designing further exploration efforts and in future reservoir development programs.

Once the knowledge is generated it is recommended that those surveys felt to be most applicable for locating the resource and developing this reservoir model should be initiated. Initial endeavors should be made to extend the Hatchobaru field if possible and to complete the exploration data base needed to delineate this reservoir.

6.6.3 Hohi II

Since no real exploration has been undertaken in this area, it is recommended that before any wells are drilled the standard exploration program be initiated. Knowledge gained from other areas particularly Hohi I should aid in the selection of applicable survey methods and design.

6.7 General Summary

This is a brief general summary of our analysis concerning the KEPCO resource exploration program results compared to a standard program.

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6.7.1

The exploration data provided has several drawbacks. The exploration programs were not utilized or implemented to their fullest potential. More effort is needed in regional evaluations and in establishing the preliminary data base. The area exploration efforts were generally too limited in design, areal extent, and did not meet the objective of fully exploring the area of interest and in establishing the data base and exploration framework to subsequently evaluate potential prospects delineated within the area. In the prospect exploration stage greater detail is needed over the prospects and additional detail is needed over features found to be of interest. This portion of the program seemed to be restricted to the regular geometric-shaped rectangular prospects (1 x 2 km), such that many of the exploration surveys were designed around them instead of being designed to locate and delineate the potential reservoir(s).

6.7.2

In the exploratory drilling program, it is felt that sufficient exploration has not been undertaken to justify drilling any wells. If more exploration had been initiated, possibly it would have been realized that KT-3 would not have penetrated the geothermal reservoir unless it was drilled deeper than 1,500 meters or that no geothermal reservoir was present. Compared to the drilling costs of approximately \$3,600,000 for KT-1, KT-2 and KT-3 it seems that a considerable amount of exploration in excess of the present program could have been done. Considering the above circumstances it also seems to be a very high risk to drill four additional wells, KT-4 thru KT-7, in this area with no more exploration data than was available for the location of wells KT-1, KT-2 or KT-3. More electrical exploration such as dipole-dipole, larger spacing Schlumberger arrays, and/or magnetotellurics should be undertaken. It is also not recommended to drill four wells simultaneously that are within 600 to 1,200 meters of each other and are within an area of 1.5 km². Even if these wells are felt to be testing different reservoirs it seems that more benefit could be gained from drilling these wells in series with each additional well location and drilling parameters based on information gained from the preceding well.

In the Standard Program each well provides information that can be used to calibrate the geophysics. Based on the well information some geophysical studies may need to be reinterpreted, additional exploration methods utilized, or other surveys may need to be re-designed before the next exploratory well is located and drilled. This may result in relocating a previously permitted drill location; however, to follow standard policy would seem to be better than the possibility of drilling a \$1,800,000, 3,000 meter well that is not in the optimal location to adequately test the subsurface of locate the reservoir.

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6.8.3

In terms of the individual surveys it appears that the major problem is that they have measured interesting near surface phenomena but have not, at present, probed deep enough into the subsurface. The D. C. resistivity Schlumberger VES surveys provided subsurface information that penetrated at the greatest only 1,000 meters and in many places depth penetration was less than this. Also the data in Kirishima was not calibrated by the exploratory wells, KT-1 thru Kt-3. These wells should have been used to aid in understanding these resistivity data.

Additional data such as deeper and more D. C. resistivity data as well as some magnetotelluric information in areas of promising electrical anomalies should be collected.

6.8.4

The proper amount of survey integration did not appear in the present data base. It is not recommended to drill for features deeper than 1,000 meters with this data. Drilling should only occur where all the data, S. P., Hg soil-air, gamma ray, etc., indicate anomalous conditions; where the aerophoto analysis, surface geology, gravity, etc. indicate recent faulting or intersecting faults for increased reservoir permeability and circulation of fluids; and especially where the electrical data is anomalously low over a sufficiently large area to indicate a potentially prospective reservoir.

It would be appropriate to drill several temperature gradient holes across this feature, both off and on this anomaly, to help support the concept of a potential geothermal feature at depth, before drilling an exploratory test well. Initially only one exploratory well would be drilled in the most prospective location to test the subsurface and to calibrate the surface exploration. If this well proved to be good, then additional exploration or drilling would be based on this well. If this well was not productive or only marginally so, then data from this well would be used to recalibrate the exploration program's exploratory well locations and improve exploration program judgments and interpretations.