GEOTHERMAL EXPLORATION METHODOLOGY

(RECONNAISSANCE AND PREFEASIBILITY STAGES)

Serial: OLADE's Documents No. 1

C O N T E N T S

1. INTRODUCTION

Following the observations and recommendations made during the VIII OLADE Meeting of Ministers held in Quito, Ecuador, from September 5 to 8, 1977, the Permanent Secretariat has placed special emphasis on a new alternate source of energy that shows a high probability of meeting the energy requirements of our Region on a medium-term basis: Geothermics.

The basic objectives of the Latin American Energy Organization, established in the OLADE Articles of Agreement signed in Lima, Peru, on November 2, 1973, are to promote the search for new sources of energy and offer the Member States coordination and guidance in this field, in accordance with the stipulations of Chapter II of the Agreement.

Acting within the terms of the Agreement, the Permanent Secretariat considers that geothermal energy has far-reaching prospects in Latin America within the framework of the development of nontraditional sources of energy.

In accordance with the above, the OLADE Permanent Secretariat has prepared a program of activities, the object of which is the planned development of geothermal resources in the Latin American countries. To achieve this aim and as a first stage of the program, OLADE has defined the general outlines of a geothermal exploration methodology, which may be adapted to the conditions and characteristics of each country. This enables OLADE to coordinate efforts for optimizing the technical, human, and financial resources available in the Region in order to establish a continuous exchange of experience and multilateral support among the countries engaged in the exploration for geothermal energy.

Thus, the Permanent Secretariat formed a group of experts who prepared a preliminary document on the methodology for geothermal exploration. The following experts participated in the work: Dr. Thomas J. Casadevall, geochemist, previously assistant professor at the Escuela Politécnica Nacional of Quito, Ecuador and at present, resident geochemist at the U.S. Geological Survey Volcano Observatory in Hawaii; Eng. Salvador García Durán, geophysicist at the Mexican Federal Power Commission, Chief of the Los Humeros Geothermal Project in the State of Puebla and previously Chief Geophysicist at the Cerro

Prieto field; and Dr. Andrea Merla geologist, Director of Geothermal Exploration at AQUATER, subsidiary of the Italian group ENI. The Chief of OLADE's geothermal program is Mr. Gustavo Rodriguez Elizarrarás, who was the coordinator of the Workshop.

The preliminary document was entitled "Proposed Geothermal Exploration Methodology," The document was circulated among the Latin American countries, some official institutions in other countries, and international organizations concerned with geothermal energy.

Due to the interest shown in OLADE's initiative, a technical Workshop was held to revise the document and evaluate its valiadity. This Workshop was held in Quito, Ecuador, from the 27th to the 31st of March, 1978, and was attended by ten Latin American contries, the United States of America, and Italy, as well as by observers from educational institutions and companies concerned with geothermal exploration (a list of participants is attached).

From the beginning, OLADE's Geothermal Program had the invaluable support of the Italo-Latin American Institute (IILA), which facilitated the participation of Dr. Andrea Merla in the OLADE Group of Geothermal Experts. Likewise, the Italo-Latin American Institute co-sponsored the Workshop. For these reasons, OLADE is pleased to have joined efforts with the Italo-Latin American Institute for the successful start of the program and in particular to have signed the Agreement of Cooperation between the two organizations, making possible future Joint actions in areas of common interest in the field of energy.

Because of the potential of geothermics as a substitute source of energy for the Andean Area, the Andean Development Corporation (CAF) helped to co-sponsor the Workshop.

In view of their experience in this area and as added support to obtain Latin American integration in the field of energy, the Mexican Federal Power Commission and Petroleos Mexicanos (Mexican Petroleum Company) also contributed to co-sponsor the Workshop.

The main results of this meeting are reflected in the present document which proposes to:

- outline the development of a typical geothermal project;

- describe the methodology which may be used during the different stages of surface exploration;

- submit a preliminary appraisal of the human and financial resources required in a typical geothermal project in order to reach the stage of advanced exploration and to establish a schedule for the different stages of the project.

Thus, this document is intented to serve as a basis of reference for the proposal of specific geothermal projects and for their development during the first stages of activity so as to optimize the use of and give preference to the technical resources of the countries.

It should be noted that the attention given to geothermics by the OLADE Permanent Secretariat is supported by technical and economic data adaptable to any country in the Region. Implementation of geothermal exploration following a program such as the one described in the present document could be useful in obtaining extra regional funds which,administered by OLADE, would ensure the start of new geothermal projects or the strengthening and support of those already under way.

Finally, OLADE wishes to express its gratitude to the above-mentioned experts who comprised the OLADE Geothermal Group and especially extends its thanks to their respective institutions for accepting the temporary absence of their experts without any benefit other than the experience they could gain.

The Permanent Secretariat acknowledges the efforts made by the administrative personnel who worked on this part of the program, especially those of Mrs. Elvia Ortega de Andrade who was responsible for the typing of the drafts and the final copy of the document.

Quito, April 1978

2. PROPOSED EXPLORATION METHODOLOGY

The exploration methodology outlined in this document is intended to give a general idea of the exploratory phases, methods, and personnel required in each phase of exploration and of the amount of investments necessary in a typical geothermal project. The proposed methodology is the result of a study of a number of geothermal exploration projects, completed or under way, in Mexico, in Italy, and in several Latin American countries, and is in accordance with the most recent scientific advances in geothermal exploration technology.

This outline is intended for countries where geothermal exploration is in its early stages. Special emphasis has been given to low-cost tools for exploration as well as to comprehensive reconnaissance studies. In establishing a schedule for exploration, an effort has been made to minimize the use, in the early stages, of intensive methods requiring costly investments.

Since there is no "universal method" for solving the problems related to the various phases of exploration for and location of a geothermal field, the most difficult aspect of the methodology is that of selecting and combining techniques which can achieve the especific objetives of each phase of exploration for each project. In fact, the wide variety of possible local conditions may require substantial changes in the sequence and/or characteristics of exploration techniques. In the evaluation of time and investment requirements, an attempt is made to account for variables such as size of prospect area, availability of local technical personnel and facilities, and the geographic conditions. Finally, the proposed exploration philosophy has been adapted to the Latin American and Caribbean geological environment.

2.1 Development of Typical Geothermal Project

In a regional sense, areas of interest for geothermal exploration are those areas of the earth's crust characterized by recent tectonic and magmatic activity such as the Andean system, the Central American volcanic cordillera, the Caribbean area, etc.

However, being located in such areas does not necessarily guarantee the presence of geothermal fields of industrial interest. Thus, in order to develop a geothermal project in these regions, which may not be well known from a geological point of view, it is necessary to undertake a field study of large areas covering between 10,000 and 100,000 square kilometers.

This reconnaissance study will result in the selection of smaller areas (between 500-2000 km^2) of specific geothermal interest and in the preliminary definition of the geologic and geothermal characteristics of each area.

Generally speaking, a typical geothermal exploration project consists of two phases (fig. No. 1): the first concerns the exploration aimed at identifying a geothermal field. The second involves futher exploration as well as technological investigations and concerns the development and exploitation of the field. The first phase involves a high economic risk and, therefore, the necessary investments should increase at each subsequent step of exploration, while overall expenditures remain comparatively low. On the other hand, the second phase involves a limited risk and requires higher investments.

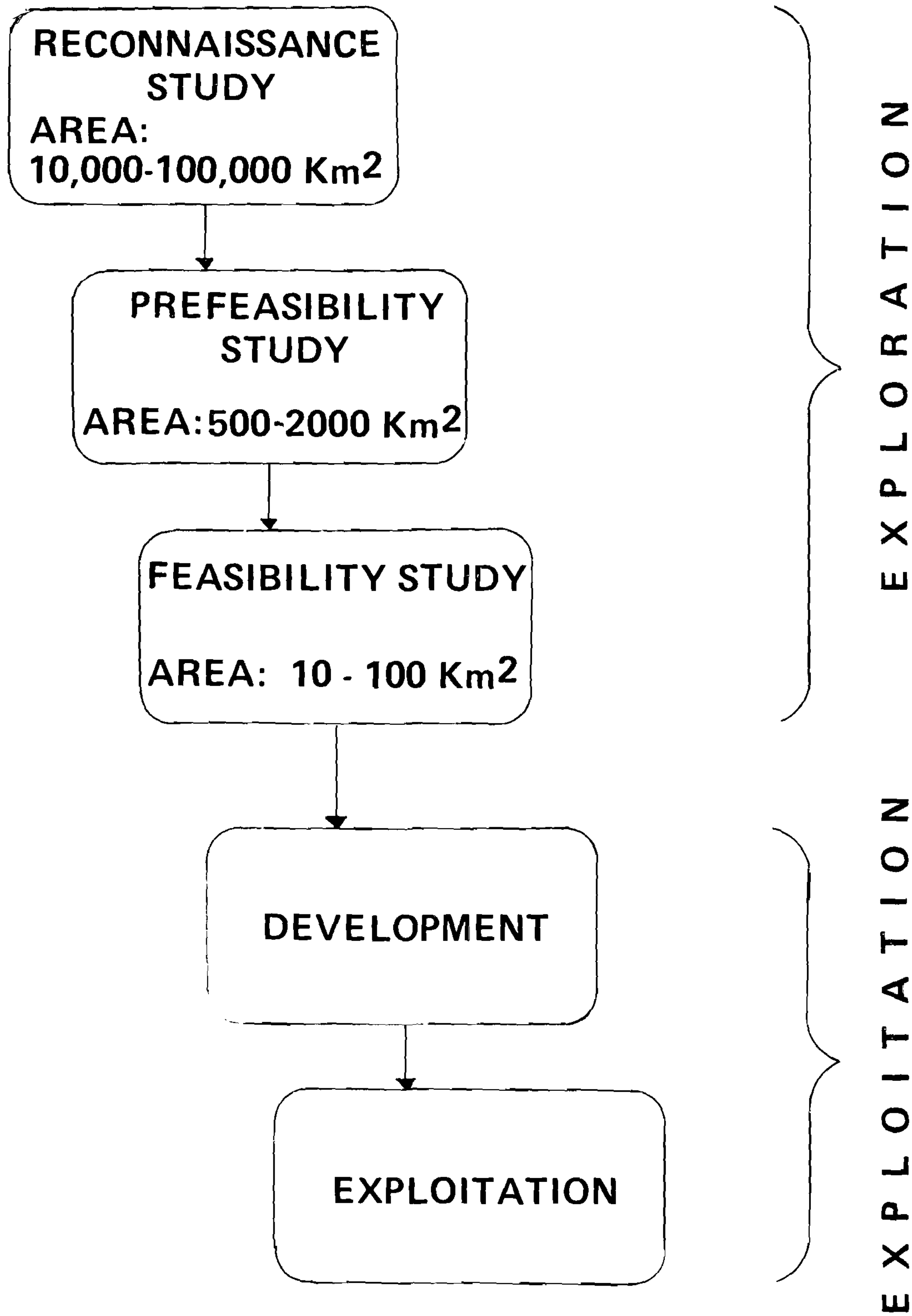
In the development of a geothermal project, after the reconnaissance studies, four main stages should be considered. The first two stages (prefeasibility study and feasibility study) concern the exploration part of the project, whereas the other two (development and exploitation) regard fluid production, its industrial uses, and field maintenance. Figure 1 shows the typical sequence of a complete geothermal project.

Experience indicates that the average surface area of a geothermal field varies between 10 and 100 km^2. If, as stated above, a geothermal exploration venture deals initially with an area of 10,000-100,000 km^2, one may identify the fields through intermediate steps, that is, the definition of a prospect area (approximately 500-2,000 km^2 and subsequently, the identification of one or more areas (100 km^2) where deep exploratory wells could be located.

The prefeasibility study should be carried out in prospect areas not exceeding 500-2,000 km^2 and should be subdivided into various phases.

FIGURE 1

PHASES OF A COMPLETE GEOTHERMAL PROJECT



Since a progressively higher level of investment is required for each subsequent phase, more expensive exploratory tools and/or detailed surveys should be carried out only over selected areas of the prospect.

Such an exploratory sequence allows the project management to discontinue study on unfavorable portions of the area and proceed to the following stage if deemed convenient.

2.2 Reconnaissance Study

A reconnaissance study consists of the evaluation of a large region through the review of all existing information and a field reconnaissance, with the purpose of selecting smaller areas of interest and of defining further exploratory steps.

2.2.1 Objectives

- Preliminary evaluation of the geothermal possibilities on a national or regional level.
- Selection of areas of interest.
- Definition of a preliminary geothermal model and the planning of a follow-up detailed exploration program for each area.

These objectives provide the technical background which, together with social, economic, and political considerations, will constitute the basis for making the following decisions:

a) What level of priority, on a national or regional level, should be given to geothermics in relation to alternative sources of energy (e.g. hydroelectricity, fossil fuels, etc.)

b) Which area should be given top priority in planning further exploration, taking into consideration both technical factors (indications of potential geothermal resources resulting from the reconnaissance study), as well as economic and social factors. Local factors may play an important role in this stage. For example, the exploitation of geothermal energy in an area where no other energy sources are available may generate other activities there, such as mining or certain types of industry requiring local availability of low-cost energy.

c) Define the amount of investment and the technical structure required to evaluate the geothermal potential of the area which has been considered of top priority.

2.2.2 Methodology

Generally speaking, a reconnaissance study on a national or regional level could be summarized as follows:

Stage I.— Evaluation of all existing information

Basic documentation will be collected during this stage, including:

- Geological maps, both detailed and on a regional scale;
- Regional geological synthesis, including stratigraphy, structural geology, volcanic history, etc.;
- Satellite and/or aerial photographs;
- Topographic maps, both detailed and regional;
- Data on the presence and characteristics of thermal springs and hydrothermal activity;
- Data available from wells drilled for other purposes (oil, water, etc.);

- All available geophysical data;

- Hydrological and meteorological data.

The evaluation of this information will enable the outlining of the geothermal provinces (geologically homogeneous areas) and defining the areas where the following stage of reconnaissance studies (field research) will be carried out.

Stage II.– Field research and laboratory analysis

On the basis of the results of Stage I, a field reconnaissance research program will be planned. Its main objective will be to collect specific data related to: 1) the possible presence of a thermal anomaly at shallow levels in the earth's crust; 2) the regional hydrogeological conditions; and 3) the nature of the thermal activity.

In volcanic regions, geological observations should be made on the following points:

- Identification of areas where a concentration of recent volcanic events exists. This concentration is clear evidence of the persistence of an important thermal anomaly in the subsurface.

- Evaluation of the relative quantity of acidic volcanic material produced by differentiation of basic magma or by anatexis.

- Definition, on a regional level, of the relation between the volcanic structures and the regional tectonics.

- Investigation of the possible presence of phreatic explosion craters.

- Collection of large number of rocks samples for subsequent analitical studies. Work on most of the samples will be limited to the study of thin sections.

– Collection of samples of xenoliths for study in thin sections.

– Determination of the absolute age of selected samples.

– Preliminary study of all possible formations, including cap rocks and reservoirs.

In the geochemical and hydrogeological field studies, water samples (cold or thermal springs, surface or well waters) should be collected in suitable containers.

The program used in these studies depends on the availability of: 1) technical staff; 2) financial resources; 3) equipment; and, 4) time. Depending on these points, two programs of geochemical study may be defined. These are the Minimum and Optimum programs necessary to fulfill the objectives of the field exploration studies. These programs include:

		MINIMUM	**OPTIMUM**
DATA REQUIRED:	Field	T°C pH Visual estimate of flow Collection of samples	T°C pH Cl or conductivity Visual estimate of flow Collection of samples
	Laboratory	K; Na; Ca; Mg; Cl; SO_4 SiO_2	K; Na; Ca; Mg; Cl; SO_4; SiO , NH_4; SiO_2 (diluted)
STAFF:		Personel not necessarily having trainning in chemistry	Person(s) trained in field chemistry, together with geologist
EQUIPMENT:	Field	Thermometer pH paper Flasks for samples and collection system	Thermometer pH paper or pH meter Cl paper or conductivity meter Flasks for samples and collection system

The chemical analyses will enable the calculation of subsurface temperatures througs the application of geothermometers such as SiO_2, K/NA/Ca, etc. Flow estimates (ltr/sec or ltr/min) are required for the use of models to determine the possible degree of mixing between thermal fluids and other surface or subsurface waters.

2.2.3 Results

Evaluation of the data obtained in Stages I and II should result in the following:

a) Definition of main geothermal provinces (e.g. areas of geothermal interest related to recent volcanism or magmatic intrusions, areas of normal geothermal gradient).

b) Selection of areas of interest. (i.e. areas indicating the probable existence of high enthalpy fluids in the subsurface, where exploitation of geothermal energy may be feasible).

Areas with low enthalpy fluids should also be indicated, since these may be used for energy generation (binary systems), as well as for nonenergy uses in agriculture, industry, and housing (district heating). The surface area of the selected zones should not exceed 500 - 2,000 km^2.

c) Definition of priority scale. Priority should be given to those areas showing the most favorable geological conditions indicating the existence of a geothermal field at an economically exploitable depth. This priority scale will be determined only on the basis of technical considerations.

d) Definition of a preliminary geothermal model for each area. This model will take into consideration the presence of a shallow thermal anomaly and the geological and hydrogeological conditions in the zone.

e) Definition of a detailed exploration program (Prefeasibility

Study).

A program of the detailed research required to better define the geothermal model of each area will be planned. The aim of this program will be to locate sites for deep exploratory wells of suitable diameter for production tests.

2.2.4 Personnel requirements, costs, and time

The first part of the geothermal exploration of a given region requires highly experienced personnel since it is during this stage that the guidelines for further exploration will be established.

Data collection (Stage I) could be made by technical staff with no special training in geothermal exploration. However, the evaluation of the data collected must be undertaken by highly qualified technical personnel, with experience in geothermal exploration. This same staff would also be responsible for Stage II of the work and should include a structural geologist, a volcanologist, a geochemist, and a hydrologist.

The time required to carry out Stages I and II may vary greatly according to the size of the region to be explored and the amount of information available.

On the average, the reconnaissance of an area of 10,000 - 100,000 km^2 should not exceed 9 to 16 months, i.e. collection and evaluation of data (2-4 months), field reconnaissance (2-3 months), laboratory analyses (1-3 months), and evaluation of results and preparation of final report (4-6 months).

The costs of a reconnaissance study should fall between a minimum of US$ 100,000.00 and a maximum of US$ 250,000.00 These estimates are subject to many factors which will be mentioned in more detail in the section on cost of prefeasibility studies.

2.3 Prefeasibility Study

Its main objective is identifying areas where deep production-size exploratory wells can be located. This phase should allow a preliminary evaluation of the possible resources.

2.3.1 Objectives

a) Define the geothermal model for the area under study.
The "geothermal model" of an area will be defined once detailed information is available concerning: 1) the presence and origin of the thermal anomaly; 2) the characteristics of cover or sealing rock formations; and 3) the type and characteristics of the "reservoir."

This type of three-dimensional model will enable planning of a suitable drilling program, aimed at testing the validity of the model.

b) Locate the site(s) for the perforation of deep exploratory wells of diameters suitable for production tests.

2.3.2 Methodology

The detailed exploration program of a given area, whose main geothermal characteristics were determined during the reconnaissance study, will consist of studies of varying cost. The emphasis on low-cost exploration should result in maximum efficiency for investment when undertaking research at higher cost.

A. Geology – Hydrology – Geochemistry

A-1) Geology and Volcanology

This work will generally start with aerophotogeological interpretation, to define faults, map volcanic structures, define volcanic-tectonic relations and fault systems related to possible hidden intrusions, and integrate existing geological maps.

The second step will be a detailed geological and volcanological survey. Its main objectives will be to:

a) Investigate the presence of a thermal anomaly at shallow levels of the crust. For this purpose, representative samples of recent volcanic rocks will be taken to obtain data on thermal anomalies at surface level (nature of the volcanic rocks, presence of differentiated rock series) and to determine the absolute age. All hydrothermal areas, both fossil and active, will be studied.

   A detailed map of all volcanic structures (central volcanoes, domes, explosion craters, phreatic explosion craters, fissural lava eruptions, and pyroclastic fields) will be compiled, and a study of volcanic geomorphology will be made.

b) Identify the cover formations and evaluate their effectiveness. This includes the mapping and sampling of all the formations showing suitable cover characteristics, both of primary origin (shales, etc.) and those due to selfsealin through hydrothermal alteration processes. In volcanic zones, emphasis will be placed on the search for phreatic explosion craters. Their presence indicates the existence of an effective cover.

c) Collect information on the presence of possible geothermal "reservoirs". All existing evidence on the presence of "reservoirs" at depths permitting economic exploration should be studied.

In volcanic zones, the sampling and study of xenoliths produced by explosive eruptions could provide information on the nature of rocks underlying the volcanic cover. In those cases, where applicable, this low-cost research enables the appraising of the lithology of the possible reservoir and the temperature and nature of the circulating fluids. This data provides information on subsurface lithology useful for other kinds of research (hydrogeology, geochemistry, etc.)

Finally, the identification and mapping of recent faults is important since they may represent good exploration targets due to their permeability.

Old faults may be completely sealed by hydrothermal processes.

In tropical countries, where rapid and heavy weathering of rocks occurs and where there is a thick layer of vegetation, geological data can sometimes be difficult to obtain through surface investigations or research may be limited to small areas.

In these cases, emphasis should be placed on the following kinds of research:

I. Morphological observations made with the help of aerophotography and analysis of satellite imagery. In many cases, simple morphological observations may give useful information on the tectonics of the area, volcanic structures, age of volcanism, etc.

II The identification of recent faults can be of great importance in these regions, since the rapid weathering of volcanic products may substantially reduce the primary permeability of older faults. In these regions, fractured zones will often be the object of geothermal exploration.

III. Airborne geophysics and remote sensing (SLAR) may be useful in tropical regions; their utilization will depend on economic considerations and local conditions.

A-2) Geochemistry and Hydrogeology

The main objectives of the geochemical program during the prefeasibility study are the following:

I. Define the regional geochemical framework for understanding of regional water circulation patterns.

II. Attempt to define the presence of a geothermal system in the subsurface, using chemical and isotopic geothermometers or detecting leakage manifestation anomalies.

The geochemical-hydrogeological program includes the following related activites:

a) Field Operations

- Visit to all points of water discharge, such as springs (hot and cold), wells, and surface waters.

- Detailed description of each water occurence, including an accurate estimate of water flow and a description of the altered area adjacent to the source of discharge.

- Sampling of water and, if applicable, gases, always in a suitable container.

- Field determination of T^oC, pH, Cl^-, conductivity, and possibly Fe^2, Ca^2, Mg^2, HCO_3, NH_4. Field analysis or adequate conditioning of the sample for later analysis is required since important changes in chemistry may occur. Field analysis must be of laboratory quality.

- Sampling of sublimates at thermal springs.

- Depending on the geological environment, analysis of soil gases (He, Hg CO_2) which may indicate the presence of a subsurface thermal anomaly.

b) Laboratory analysis

The extent of the laboratory analysis depends on the geological environment and normally requires determining 12 to 18 components. Sublimate identification may be made by chemical or X-ray analysis.

c) Interpretation

Processing of analytical data will result in the identification of the main types of water according to their chemical characteristics as well as the existence of mixed waters; an interpretation of the origin of the thermal waters, mapping of leakage anomalies and calculation of the reservoir temperature. Data processing and interpretation may be facilitated by computer analysis.

B. Geophysics – Shallow Wells

B-1) Geophysics

Geophysical exploration techniques have three main objectives:

I. Determining the regional geological and structural conditions in the zone where the goethermal resources are located.

II. Locating and defining the thermal anomalies.

III. Determining particular structural conditions.

For the first objective, a gravimetric study and perhaps a magnetometric or aeromagnetic study constitute the most appropriate tools for defining the main geological structures in the zone. The geophysical exploration using these techniques can be undertaken while the studies listed under "A" are being carried out; that is, as soon as the most relevant geological conditions are known.

For the second objective, traditional electrical methods, geoelectrical resistivity maps and/or profiles can be used to analyze the resistivity variations associated with possible zones of anomalous temperature. A semi-detailed resistivity study may be planned when suitable knowledge of the geological conditions of the zone is available; on the basis of this study, a more detailed survey will be planned.

The use of other techniques (electrical, electromagnetic, seismic noise, etc.), should be considered at present as being experimental techniques, without discarding the possibility of their future use.

For the last objective, geoelectrical techniques (vertical electrical scanning), active seismic measurements (reflection or refraction), passive seismic detection (microtremors) and others can be used to determine particular geological conditions such as: cap-rock thickness, depth of particular geological units, determination of active faults, etc. The use of any of these techniques will depend on the specific problem to be solved and the cost-precision relation desired.

B-2) Drilling of multipurpose, shallow test holes

The program of shallow test drilling will be planned after attaining sufficient knowledge of the geological and hydrogeological conditions. The number, location, and depth of test wells will be such as to gather maximum information with minimum investment. These wells should provide decisive elements for the definition of the geothermal model of the area.

The depth of these small diameter holes depends on geological-hydrological conditions. They must reach and penetrate the impermeable cap-rock directly overlying the specific target reservoir, if predicting the reservoir temperature is the objective. However, assessing geothermal gradients by assuming that they are determined by a conductive heat transfer process has led to numerous failures, because this process is not always the case, and extrapolation of shallow thermal gradients may be misleading.

Sampling water and gas at non-disturbed horizons, structural correlations, and revised estimates of temperature at depth are examples of other objectives of this drilling program.

It is difficult to set standards for the most suitable drilling depths under these circumstances; the decision depends on an assessment of the expected information gained relative to the overall cost of the program.

Generally speaking, however, the objectives of these wells are one or more of the following:

- Collect a series of temperature measurements in order to calculate thermal gradient and predict temperature at depth;

- Collect rock samples for conductivity measurements (heat flow calculations);

- Collect, for geochemical analysis, samples of the fluids which may be encountered in order to study the possible presence of convective processes which may alter the wallrocks and to compare water chemistry with surface geochemical studies.

- Measure values of electrical resistivity through the drilled section, to correlate with the surface electrical resistivity surveys.

- Study of the stratigraphic sequence.

It should be stressed that estimates and extrapolations of the geothermal gradient, temperatures, and production prospects can be made only with a detailed knowledge of the surface geological, hydrogeological, and geochemical conditions.

2.3.3 Personnel requirements, costs, and time

The number of technical personnel required for the completion of each phase depends on the local situation. However, it is possible to give a general idea of the organization and the time requirements. Assuming an area of 500 -2,000km^2 and the existence of basic information such as: detailed topographic maps, geologic maps and aero-photo coverage.

A. Personnel

The following is a summary of manpower necessary for carrying out the prefeasibility study.

– Geology and Volcanology

Photogeological interpretation	1 photogeologist 1 technician analyst
Field work	1 geologist 1 volcanologist
Laboratory work	1 petrologist
Data processing and reports	1 geologist 1 volcanologist
Supervision	1 geologist expert in geothermal exploration

– Hydrogeology – Geochemistry

Field work	1 hydrogeologist 1 geochemist 1 technician analyst
Laboratory work	1 geochemist 1 technician analyst
Data proccesing and reports	1 geochemist 1 hydrogeologist

	1 computer technician
Supervision	1 geochemist, expert in geothermal exploration

- Geophysics

  Regardless of whether the geophysical surveys are made by locally available personnel or on a contractual basis, the management group should include at least one geophysicist, expert in geothermal exploration, for program supervision and interpretation of geophysical surveys.

- Shallow test holes

  A contractor will be used for drilling or at least to provide drilling equipment. If a contractor is used, the project management should provide the necessary personnel for drilling supervision, test hole measurements, and data analysis; this personnel includes:

  1 geologist
  1 geochemist
  1 geophysicist

- Prefeasibility final report

  This report will be prepared by all of the project personnel, including a drilling engineer. Geothermal experts with exploration experience should be consulted for a better analysis.

B. Time

The following summary of the technical times considers the average time of some geothermal exploration projects in Latin American countries.

Geology – Volcanology (field work, laboratory analysis, reports)	9 – 15 months
Geochemistry – Hydrogeology (field work, laboratory analysis, reports)	9 – 15 months
Geophysics (field work, interpretation, report)	9 – 15 months
Shallow test holes* (drilling, measurements, report)	7 – 16 months
Final report	4 – 6 months

The total time of a prefeasibility study, considering the fact that some activities could be done simultaneously, varies in a range of 20-30 months. However, those times could be reduced by optimal utilization of personnel.

C. Costs

Costs of an exploration program, as outlined in the foregoing chapters, will vary according to several factors:

– The amount of available geological and hydrogeological information;

* Average total of 2,000 m. of drilling in multiple wells

- The existence of local trained and expert technical personnel:

- The geographical and geological characteristics of the region under study.

- The local existence of adequate laboratory and computing facilities.

An estimate of cost is, therefore, very difficult to make due to the variation in these factors. Nonetheless, an attempt is made to define the range of necessary costs.

The philosophy followed in estimating costs is based upon two principles:

a) Emphasis is placed on low-cost exploratory tools, such as volcanology and geochemistry. These methods provide important information which may preclude the use of more expensive methods;

b) When a certain stage in exploration is reached, increased investments will provide only little advancements in the understanding of the geothermal system. At this stage the decision to start deep-production-size drilling should be taken.

The range in the following cost evaluation also takes into account several variables such as: availability of local expert personnel, number of local personel, number of foreign personnel, and geographical conditions.

Total estimated cost of the prefeasibility studies, considering an area between 500 – 2,000 Km^2, will be:

Minimum of 800,000 US$
Maximum of 1,600,000 US$

Once the prefeasibility study is finished, and if the results are favorable the exploration program continues to the last phase of study the Feasibility Study.

The Feasibility phase of geothermal exploration has the following objectives: the delineation of the geothermal field; the evaluation of exploitable reserves; the preliminary estimate of available resources; the study of the geothermal fluid(s) and their possible uses; and the setting up of a pilot plant or generating facility

The Feasibility Study includes the first exploratory wells, the reservoir studies, investigation of various production programs and alternate methods of fluid utilization, economic studies and, finally, the design of the pilot plant.

In this document, only the first two phases of a typical geothermal exploration program have been analyzed; these are the Reconnaissance and Prefeasibility Studies. The analysis of the Feasibility Study will be the subject of another document.

3. DESCRIPTION OF MAIN EXPLORATORY METHODS

3.1 Geological Exploration in Volcanic Areas

A geothermal field suitable for exploitation, that is, for the production of vapor for electrical energy generation or for the production of hot water (low enthalpy) for non-energy uses, should have the following principal characteristics:

- A thermal anomaly.
- A reservoir of permeable rocks within which the geothermal fluid circulates. The reservoir should be at a depth to make its exploitation economic.

– An impermeable cover above the reservoir to prevent the loss of heat by convection of fluids toward the surface.

3.1.1 Heat sources

In many volcanic regions the heat necessary for the formation of a geothermal system near the earth's surface can be supplied essentially by a mass of magma having a high temperature, situated in the earth's crust, such as an intrusion in the process of cooling or a magma chamber feeding a volcano. Theoretically, all zones affected by recent volcanic phenomena are potential geothermal locatilities. In reality, the only areas of practical interest are those where a large volume of magma is found at relatively shallow depths (less than 10 km).

Thus, areas in which magma has risen directly and rapidly from the mantle through fissures, such as plateau basalts, are of less interest.

Also, those areas where large volumes of magma are presently located within the upper part of the continental crust (i.e. acidic magmas originated within the crust itself) or areas containing large central volcanoes linked to magma chambers are considered to have geothermal potential.

In the preliminary exploration of a geothermal region, the problem of locating a thermal anomaly near the surface should be tackled through volcanological, structural, and petrological methods. These methods are aimed at distinguishing central volcanoes, evaluating their significance in the regional structural framework and estimating their ages using morphological criteria or measurements of absolute ages using radiometric methods. The presence of active fumaroles in the crater of a central volcano is the best indication of the recent age of the volcano. However, the crater of an active volcano is not amenable to exloitation with present technology.

Petrologic studies of lavas and other volcanic products are aimed at defining the nature of the magma, in particular its degree of acidity and differentiation. Such data are essential in order to evaluate the possible existence of near-surface magma chambers which feed the volcano and to estimate if the nature of the magma implies the presence of a shallow thermal anomaly within the earth's crust. The latter is the case of magmas formed by crustal anatexis, (i.e. by partial melting of the upper continental crust, a process that requires anomalously high temperatures at moderate depth).

The formation of magma chambers with a thermal capacity sufficient to heat a large volume of rocks requires favorable tectonic conditions, such as intersection of faults or tilting of fault blocks forming tectonic traps where the rising magma rests and differentiates. Thus, the relationships between volcanic structures and tectonic lineaments should be investigated to recognize the ocurrence, at shallow depth, of hot magma bodies.

Favorable elements are the long persistence of volcanic activity through time and the frequent eruption of strongly differentiated products whose formation requires a long residence time within the magma chamber. In most cases, magma chambers are the feeding reservoirs of complex central volcanoes, volcanic structures built around a central vent by the eruption of products genetically related through fractional crystallization.

In other cases, only the most evolved and differentiated magmas reach the surface through fissural eruptions of differing intensity, forming either volcanic fields, with several monogenic centers (as in Phlegrean Fields, Italy), or more importantly, pyroclastic eruptions.

In other cases, the magma may remain at shallow depths without producing volcanism. However, its emplacement in the upper crust may affect the surface structures with the formation of horst structures, usually with minor collapses or radial or concentric fault systems (as in Larderello, Italy).

3.1.2 *The reservoir*

The reservoir is formed by rocks of high permeability with a sufficient volume of rock to assure a prolonged exploitation. Also, the reservoir should be located within a favorable hydrological system. Delimitation of the reseroir is the most difficult problem of geological exploration due to the presence of wide-spread surface volcanic cover which may prevent study of deeper substrata. This requires knowledge of the general geological setting, particularly of the thicknesses, depth, lithology, and permeability of the various stratigraphic units found beneath the volcanic cover. In many cases, stratigraphic studies and geologic mapping may provide important information concerning the reservoir. The identification of areas of highest fracture permeability due to tectonism and the pattern of distribution is also very important.

Important information can be obtained from the study of the xenoliths in volcanic rocks. These are samples of the subsurface rock units, and their study may provide evidence for hydrothermal alteration phenomena produced by the circulation of fluids at high temperature.

Xenoliths of buried rocks occur preferentially in explosive volcanic products (ignimbrites, and tephra or tuffs). Both fresh and altered xenoliths must be collected and studied; particular attention must be given to the observation of textural features of hydrothermal minerals (in veins, or randomly distributed) and to alteration mineralogy which may indicate changes in the chemico-physical conditions of the circulating fluids.

Finally, the evaluation of a reservoir (lithology, depth, structure) involves the use of geophysical methods. One of the main objectives of geological exploration is to evaluate the best geophysical methods for use in exploration, based on the local geological characteristics.

3.1.3 The cover

The cover should consist of an impermeable sequence of rocks. These may be sedimentary rocks with primary impermeability (clay, silt, lacustrine deposits) such as in Cerro Prieto, México; Larderello, Italy, and Wairakei, New Zealand, or rocks with secondary impermeability (self-sealed) due to the prolonged effects of thermal activity, as in the case of the Geysers, USA, or Otake, Japan. To define the cover it is necessary to understand the subsurface stratigraphy. This problem can be approached on a purely geological basis, although geophysical methods are often necessary to evaluate the thickness of the impermeable unit. In addition, ascertaining the presence of an impermeable sequence near the surface is essential in determining the utility of shallow drill holes for measuring the geothermal gradient in the later stages of exploration. These holes are useful only when they penetrate the impermeable strata where the distribution of the temperatures is not altered by the circulation of ground water. This drilling is economic only if the impermeable layers are not too deep.

3.1.4 Surface manifestations

In regions where the cover is fractured by faults, the geothermal fluid may rise directly to the surface, producing various thermal manifestations (hot springs and fumaroles). The presence of such manifestations is an indication of the possible existence of a geothermal field. However, such indications are not absolutely essential; geothermal fields (Los Humeros, Mexico) may exist without surface manifestations. Also, there are hot springs that are unrelated to high enthalpy fluids such as those related to waters that rapidly rise along deep faults in areas with normal geothermal gradient.

The study of surface manifestations must be made within the general hydrogeological framework. On one hand, this implies a knowledge of the hydrology of the region (rainfall pattern, underground circulation), of the main structures controlling the hydrothermal systems, and of the structural characteristics of each spring; and, on the other, it requires detailed geochemical exploration. The geochemical study aims at supplying data for the hydrogeological model and at detecting leakage manifestations from the geothermal reservoir. Other useful information can be obtained from the study of the fumarolic sublimates.

3.1.5 Phreatic (hydrothermal) explosion craters

A particularly significant element in a geothermal region (not necessarily a volcanic one) is the frequent presence of phreatic explosion craters (hydrothermal). These structures are produced by the explosion of pockets of heated steam held under pressure by an impermeable cover. Their presence indicates that all the basic elements of a geothermal field (impermeable cover, fluids at depth, heat anomalies) are present in the zone affected by the explosion. Therefore, these structures must be carefully searched and their age estimated.

3.2 Geochemistry

A geothermal area may be considered to be a chemical system at high temperature. The main components of this system are a fluid phase (the liquid water; vapor), and a complicated, heterogeneous solid phase (the wall rock). Two major types of geothermal systems have been recognized based on the physical state of the dominant pressure-controlling fluid phase. These are hot-water systems in which liquid water is the pressure-gradient controlling fluid phase; and vapor-dominated systems in which liquid water and vapor normally co-exist in the reservoir, with vapor as the continuous, pressure-controlling phase. Vapor-dominated systems are preferable over hot-water systems for energy generation for a variety of engineering and economic reasons. Unfortunately, vapor-dominated systems are much rarer than hot-water systems. In hot-water systems, the chemistry of the fluid phase bears a direct relationship to the underground reservoir of thermal water and the enclosing rock. Because of the high temperature, chemical reactions between the components should attain equilibrium at a relatively rapid rate. The chemistry of the fluid in a hot-water system reflects a state of "last equilibrium" between the fluid and the wall rocks of the reservoir and can be interpreted accordingly. The chemistry of fluid from a vapor-dominated system, however, does not usually have a direct relation to the underground reservoir due to fluid boiling and the resulting presence of two fluid phases, liquid and vapor. However, in this case the presence of a high temperature fluid is already established.

Geochemical studies during the prefeasibility stage of exploration are useful in:

a) Determining the variability in the geochemical environment by recognizing the types and interactions (mixing) of different waters and gases based on their chemistry. This results in a grouping of surface waters, ground waters and thermal waters by chemical type and permits the "fingerprinting" or characterization of the possible target reservoir(s) on the basis of water type.

b) Determining the origin of the fluid phase as well as the location(s) of recharge area(s) by considering the hydrogen and oxygen isotope chemistry of the waters.

c) Recognizing the distribution patterns of particular elements. Such patterns could result from the dispersion of those elements away from a heat source or, more generally, a geothermal system.

d) Estimating the minimun temperature in the target reservoir by using various geothermometers and mixing models.

e) Recognizing the chemical problems related to the production and disposal of waste fluids,including both waters and gases.

3.2.1 Program scheme and methodology

The geochemical program consists of three activities: 1) field; 2) laboratory; and 3) data processing and interpretation.

The relationships between these activities is presented diagramatically in Figure 2.

a) Field activities

Field studies are necessary to collect water, gas, and sublimate samples for laboratory analyses and also to measure variables such as T°C and fluid flow, which cannot be measured in the laboratory. It is advisable to take to the field portable laboratory kits for measurement of pH, NH_4, Fe^{+2}, dissolved gas in water, and for gas analysis and sampling.

b) Laboratory activities

Laboratory studies include the analysis of samples collected in the field. The following elements and compounds should be determined in water:

Cations:	Ca, Mg, Na, K;
	Li, Rb, Sr, Cs, B;
Anions:	Cl, SO_4, HCO_3;
	F, Br.

Gas samples should be analyzed for O_2, N_2, Ar, CO_2, H_2, He, CH_4 and other hydrocarbons.

Information on the origin of the thermal waters may be obtained from measurements of oxygen ($^{18}O/^{16}O$) and hydrogen (H/D) isotope distribution.

c) Data processing and interpretation

Computer processing of data is aimed at sorting out the large amount of numerical and nonnumerical information made available. Use of a computer facilitates analysis selection, statistical computations, list and table printing for reports, plotting of chemigraphic relations, etc.

Some of the objectives sought during interpretation of geochemical data include: mixing model, water/rock interaction, and more generally, an understanding of the processes leading to the observed water composition. Factor analysis is usually performed to identify processes or to handle a large variety of data. Thus, reservoir temperatures may be calculated, leakages from prospective reservoirs may be detected, and -on occasion -the relative value of the geothermal gradient over adjoining areas can be assessed.

Interpretation of data is facilitated by rapid and comparatively inexpensive production of a variety of records and calculations that may be done by computer.

3.2.2 Techniques

In this section a brief description of the various techniques for geochemical study is given. It should be noted that techniques of geochemical prospecting are constantly being invented, revised and improved. Therefore, specific methods are not discused in detail. The actual implementation of these methods depends on a number of factors, such as location of and access to the area, manpower and equipment availability, and budget allowances. Depending on meteorological factors, such as annual rainfall variation and rate of evapo-transpiration, it may be necessary to sample a prospect area more than once during a year to have an accurate understanding of its geothermal potential.

a) Field

The field study must be performed by a trained geochemist familiar with the problems and pitfalls of field measurement and sampling. The following table summerizes the types of measurements needed, equipment, and approximate equipment costs:

MEASUREMENTS		EQUIPMENT	COSTS
1)	temperature (±0.5°C)	Thermometer	\$ 20 – 100 each
2)	pH (± 0.1 pH unit)	pH meter	\$ 300. each
3)	conductance	Conductance meter	\$ 300. each
4)	alkalinity	Alkalinity kit	\$ 200. each
5)	Flow estimate	(Visual estimate)	
6)	alkalis (Ca, Mg)	Field kit	up to \$ 1,000 each kit
7)	NH_4, CO_2	Field kit	\$ 1,500–3,000 each kit
8)	sample collection	Bottles, reagents	\$ 1,000

b) Laboratory

The accurate analysis of collected waters and gases and the identification of sublimates are perhaps the most indispensable aspect of the geochemical studies. Analyses should be made as rapidly as possible following collection, especially for gases, by laboratories familiar with water and gas chemical analyses. Meeting the specifications required for geothermal exploration takes a sizeable amount of time and effort, even by highly qualified laboratories. The following laboratory equipment is the minimal necessary to perform the requisite analyses:
1) atomic absorbtion (AA); 2) gas chromatography; 3) wet chemical analytical facilities; 4) spectrophotometry.

When local facilities are not available, it is strongly recommended that the chemical analyses be done on a contractual basis by a reliable and experienced laboratory. A system by which randomly selected samples are analyzed by other laboratories is recommended to provide a check on the accuracy of analytical results. This method of cross checking results is common practice in other applications of geochemical exploration. In the event that contractual arrangements cannot be made for analyses, an experienced aqueous chemist should be an integral member of the geochemical team, supervising all sample preparation and chemical analysis.

Complete chemical analyses can be done on a bulk, contractual basis for between $ 100 and $ 200 per sample. Hydrogen and oxygen isotope analyses can be performed, when and where needed, for about $ 150 per sample. When used, gases must be analyzed for O_2, N_2, CO_2, H_2S, He, H_2 and methane. In special cases, heavier hydrocarbons, CO, rare noble gases (Ne, Xe, Kr) may also be required. Gas analyses of this type range from $ 50 to $ 200 per sample.

c) Data processing and interpretation

Upon completion of the field and laboratory studies, a large number of measurements of the various physical and chemical parameters of the geothermal system is available. The handling of this data may be facilitated by using the computer.

Data processing may include:

- Checking the chemical analyses for internal consistency.

- Statistical calculations, such as: means, standard deviations, measures of correlation among variables, etc.

- Plots of significant two-variable correlations.

- Multi-variate regression analysis, factor analysis, and preparation of graphic documents.

Processing and documenting the data as outlined serves for the purpose of interpretation. Water type distribution and geochemical processes going on in the system(s) under study may be discovered and documented in this way. Only then will implementation of such exploration techniques as geochemical thermometry, detection of leakage manifestations, and mixing model calculations be meaningful.

Based on these studies, an internally consistent hydrogeochemical and thermal model of the geothermal system may be assembled. This model must meet the constraints set by geological and geophysical as well as by geochemical data. The refinement of this model is an iterative process, continually incorporating the results of later geochemical, geological, and geophysical studies up to and including the development and exploitation stages of the geothermal program.

Several of the questions which such studies can help to answer include:

- Identification of water types based on chemistry;
- Aquifer identification and their role in the regional circulation of water;
- Leakage studies.
- Geothermometry
- Mixing models

Leakage studies

The recognition of leakage manifestations (the release of geothermal steam to the surface) and detection of leakage anomalies (geochemical anomalies resulting from the release of geothermal steam and/or gases where surface manifestations do not occur) are an important part of the geochemical studies since small mixtures of geothermal steam and/or reservoir gases in surface waters can be detected. The best studied indicators of leakage are ammonia (NH_4), boric acid (H_3BO_3), and reservoir gases (CH_4, H_2S, CO_2, H_2, He, Ar-40). Leakage studies provide valuable information on both hot-water and vapor-dominated systems.

Due to the presence of both steam and liquid water in the vapor-dominated system, the chemistry of the steamfield condensate may not have a direct relation to the underground reservoir of thermal water, except with regard to its volatile components. Boric acid and ammonia are common in fumarole discharge and become concentrated in the condensed water. Due to the relatively low volatility of boric acid and the high reactivity of ammonia with near surface clay material, these components are not carried long distances in the steam phase. Where present, these components may show continuous gradation within the prospect area,which would indicate the zone of most intense subsurface boiling. Computer processed statistical analyses would test the significance of the leakage data as well as indicate the presence or absence of leakage anomalies in the study area.

Geothermometry

An important goal of geochemical studies is the estimation of the temperature distribution in the reservoir. In hot-water geothermal systems, reservoir temperatures can be estimated from the chemistry of the surface springs. The two most popular geothermometers are SiO_2 content and the K/Na/Ca atomic ratios. These geothermometers have been calibrated both empirically and experimentally. They assume that fluid chemistry reflects equilibrium between the fluid and the reservoir wall rock via temperature-dependent chemical relations. Other geothermometers such as Mg content; Cl content; Cl/F ratio; Ca and HCO_3 contents have not been calibrated and provide only semi-quantitative estimates of reservoir temperature.

A problem for leakage studies and, more importanly, for geothermometry is the requirement of comparatively pure samples of reservoir fluids for analysis. Other assumptions which must be made for geothermometry include; negligible reaction of the fluid with wall rock while in transit to the surface so that reservoir composition is retained; absence of dilution or mixing with other waters at intermediate levels; and rapid flow of water from the reservoir to the surface. Such assumptions do not hamper leakage studies which are interpretable in terms of mixing models.

Mixing Models

Where the surface manifestations of a geothermal system are mixtures of hot water from deep in the system and cold, shallow ground water, hot spring water composition and flow characteristics may be appropriate for the application of mixing models to estimate the temperature and salinity of the high-temperature component of the mixed water. The estimated temperature is commonly higher and more accurate than the maximum temperature indicated by mixing. In some places mixing models have indicated the existence of different reservoirs (permeable zones where residence times of water in the rock are long enough and temperature hot enough for water-rock chemical equilibrium to be attained) with different temperatures and compositions in different parts of a single connected hydrothermal system.

3.2.3 Costs, equipment, and manpower

Geochemical studies are highly cost-efficient when compared with other phases of geothermal exploration such as geophysics and exploratory drilling. The following table is an estimate of costs, equipment requirements, and manpower for the prefeasibility study of an area (1) selected from the reconnaissance phase.

(1) Area of 500 to 2,000 km^2.

APPROXIMATE COSTS (1977)	EQUIPMENT	MANPOWER/TIME
FIELD (excluding salaries for local personnel) $ 3,000 to $ 4,000 for equipment $ 7,500 ./month for expert consultant	thermometer PH meter conductance meter alkalinity kit Ca, Mg, NH_4 kit sample collection equipment, including bottles and reagents	1 geochemist (expert) 1 field assistant (2 to 6 months)
LABORATORY $ 100 - 200 per sample for elements and compounds $ 150 per sample for hydrogen and oxygen isotopes $ 50 - 200 per sample for gas analyses	When local facilities are not available, it is recommended that chemical analyses be done on a contractual basis. The following equipment is the minimal necessary to perform the requisite analyses: 1) Atomic absorbtion (AA); 2) Gas chromatography; 3) Wet chemical analytical facilities 4) Spectrophotometry	(2 to 4 months)
DATA PROCESSING AND CALCULATION $ 1,000 to 2,000 for computer time rental (Costs if calculations made by computer) $ 7,500. per month consultant	Computer time rental	1 geochemist (expert) 1 data processor (1 to 2 Months)

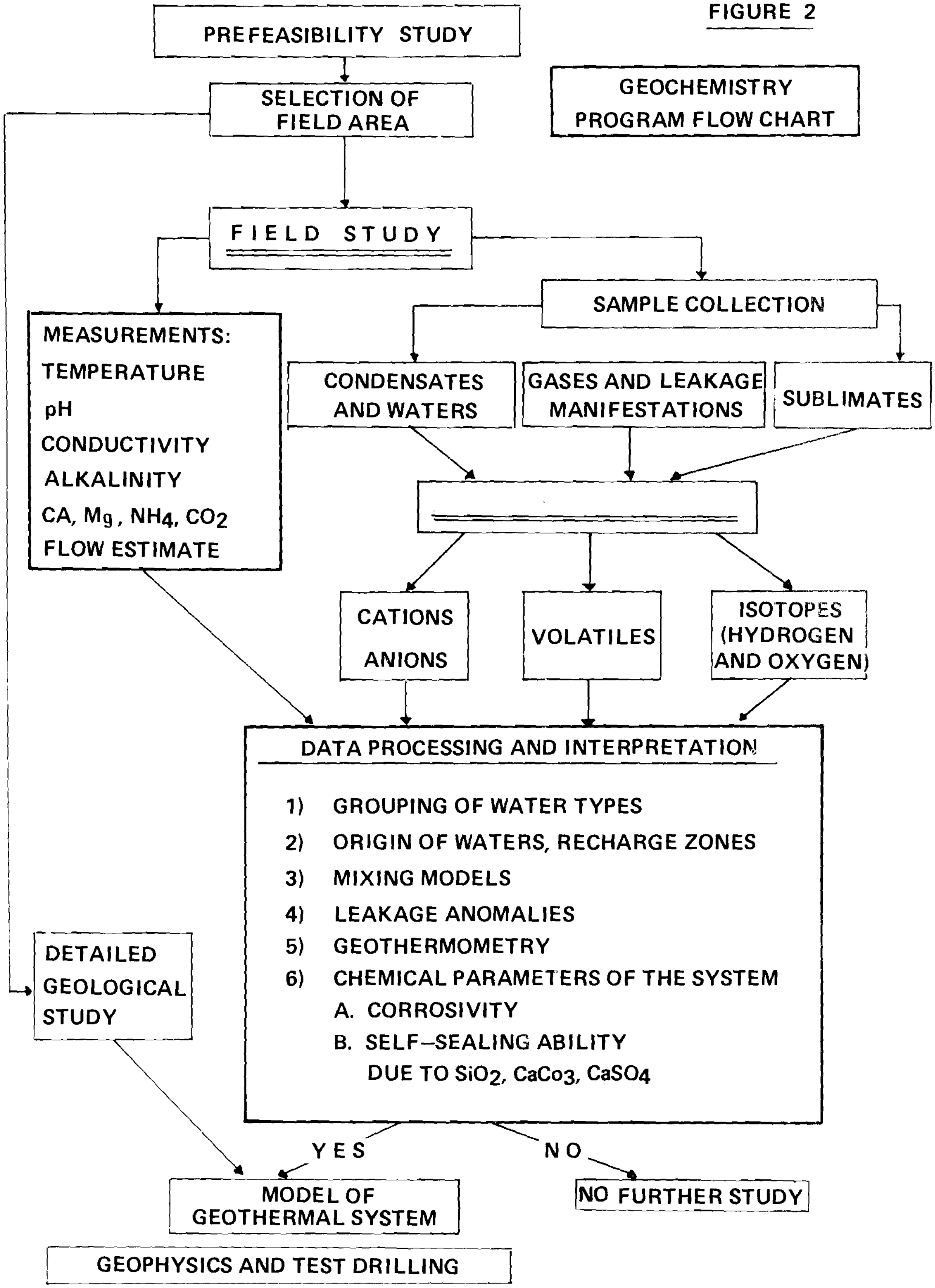


FIGURE 2

GEOCHEMISTRY PROGRAM FLOW CHART

3.3 Geophysics

The object of geophysical studies in geothermal exploration is to contribute to the other preliminary studies (i.e. geology, volcanology, hydrology, and geochemistry) in the preparation of a model of the geothermal system of the area under study; by:

a) Determination of the regional geological and structural conditions;

b) Location and delineation of thermal anomalies;

c) Definition of particular structural features.

Geophysical exploration methods are based on the measurement of the variation, in time and space, of some of the physical properties of the rocks, such as density, magnetic susceptibility, elasticity, and electrical and thermal conductivity.

Analysis of these variations permits a qualitative and/or quantitative interpretation which, together with the other preliminary studies, is used to formulate a three-dimensional model of the geothermal area.

3.3.1 Geophysical exploration methods

a) Determination of the regional structural conditions

Within the framework of geothermal exploration, gravity and magnetic data have been used primarily to delineate the geological and structural conditions within which the geothermal resource is situated. A qualitative interpretation of gravity and magnetic maps may indicate the framework of the major geological structures. A quantitative interpretation is reached through rigorous mathematical treatment of the data using a computer.

The planning and the results of these surveys depend on the geological information previously acquired on the study area.

A gravimetric survey will provide, at a relatively low cost, important information on the regional structural framework.

b) Location and delineation of thermal anomalies in the study area

To date, the greatest success in locating and delineating geothermal fields has been achieved using electrical and electromagnetic methods (resistivity, telluric, magnetotelluric, and other techniques).

Regional geothermal exploration has been carried out by examining resistivity anomalies due to the presence of areas of anomalous temperature. A correct interpretation should consider that the electrical resistivity of rocks is affected not only by temperature, but also by porosity, salinity, pressure, and mineral alteration.

Direct current resistivity mapping, using different configurations (Schlumberger, Wenner, Bipole-Dipole) have been used to delineate the zone(s) of thermal anomalies.

Other electrical techniques, such as: telluric, magnetotelluric, audio-magnetotelluric, and other geophysical techniques (seismic noise, i.e.) used to locate thermal anomalies or geothermal systems are still in an experimental stage. However, their possible future use cannot be dismissed.

c) Definition of particular structural features

Depending on the specific problem, several geophysical techniques may be used to define particular conditions at a local scale. Gravimetry and magnetometry have in many cases provided very detailed structural information. In some cases the gravity anomalies are directly related to the reservoir of hot fluids and rock. Information on the igneous rock related to heat source may be obtained with a magnetic survey.

In addition, gravity and magnetic data have other specialized applications in geothermal exploration. For example, specific information can be obtained on: the location of faults, fractures and/or alteration zones; mass anomalies directly related to the temperature of a volume of rock; and changes in density of a geothermal field due to mass transfer during exploitation.

Both active and passive seismic methods may be helpful in solving a particular problem. These methods are based on the analysis of the travel paths of elastic waves generated at the surface. Active seismic methods will often provide decisive information on the location of geological contacts.

In geothermal exploration, seismic methods have been used little, mainly due to their high cost. However, reflection and refraction studies have been made in some areas to define particular geological conditions (depths and thicknesses of rock units, location of faults, etc.). Recently, seismic activity studies of a geothermal field (microearthquake surveys) have been used to determine active fault zones. Studies of the velocity attenuation of P and S waves, time delays, and relative spectra, among other wave characteristics, are being carried out as possible tools for determining the location of magma chambers.

Considering the cost-efficiency relation, resistivity techniques (vertical electrical sounding) have been used quite successfully to determine the depths of particular geological units, i.e. cover thickness layer.

3.3.2 Final considerations

The implementation of any geophysical study requires qualified personnel and adequate equipment. For these reasons, with few exceptions, geophysical surveys have generally been contracted to specialized companies.

If this is the case, it is essential that a geophysicist, expert in geothermal exploration, be included among the project personnel. He will be responsible, together with the geologist, the geochemist, and the hydrogeologist, for the definition of the exploratory program to be carried out by the contractor.

Establishing the program of geophysical exploration to be carried out on a specific geothermal prospect is a delicate matter, given the variety of possible geologic conditions. The geophysical program should be based on the preliminary geothermal model of the area resulting from previous geologic, hydrogeological, and geochemical exploration. While the geophysical methods used to define structural conditions and, in some cases, thermal anomalies have given excellent results, other techniques used in the outlining of a geothermal field should be considered as being in an experimental stage. It must be emphasized that the project should include at least one experienced geophysicist, who will be responsible for the planning, supervision, and interpretation of the geophysical studies.

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