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Cerro Prieto-001

MEXICAN-AMERICAN COOPERATIVE PROGRAM AT THE CERRO PRIETO GEOTHERMAL FIELD

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DISCLAIMER

ABSTRACT

On July 21, 1977, the Comisión Federal de Electricidad of Mexico and the U. S. Energy Research and Development Administration (now part of the Department of Energy) signed an agreement to conduct a cooperative study of the Cerro Prieto geothermal field, located approximately 35 km (20 miles) south of Mexicali, Baja California, Mexico. The Coordinadora Ejecutiva de Cerro Prieto is organizing all Mexican participation in this project. The Lawrence Berkeley Laboratory is coordinating technical activities of all participants from the United States.

The Cerro Prieto project incorporates studies of the geologic, hydrogeologic, geochemical, and geophysical setting of the geothermal field as well as its structural, reservoir engineering, and subsidence characteristics. A description of the activities involved in each part of this cooperative program is presented. Results will be forthcoming in the form of technical reports, workshops, and scientific meetings.

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1.0 INTRODUCTION

Large scale exploitation of geothermal energy has been attempted in relatively few areas of the world. Most of the known geothermal fields are of the so-called liquid-dominated type—producing a mixture of hot brines and steam. According to White and Williams (1975, Table 26), the identified liquid-dominated geothermal systems have a much larger heat content than the identified vapor-dominated systems, 715 X 10^{18} cal vs 26 X 10^{18} cal, respectively. However, most geothermal power at the present time is generated from vapor-dominated systems—producing only steam. The Geysers, with 502 MWe in California, and Larderello with 381 MWe in Italy are the best known examples. The reason for this is that the development of geothermal power from liquid-dominated systems is technically more difficult than from vapor-dominated systems. Some of the main problems encountered with liquid-dominated systems are: (a) larger masses of fluids must be produced to generate a given amount of electrical energy; (b) corrosion of well casing and piping may be excessive; (c) precipitation of minerals from the brines may be considerable; (d) large pore pressure drops in the reservoir rock may result in subsidence at the ground surface.

None of the presently producing liquid-dominated geothermal fields has been adequately documented in the literature. There is only scant information on the technical problems encountered in field exploration and development activities and how these difficulties were solved. In addition, an understanding of the behavior of these systems under full-scale development is lacking.

A significant number of the high temperature (T > 150°C) liquid-dominated systems in the United States are located in the Imperial Valley of California. Just across the border in Mexico lies Cerro Prieto, which is in the same geologic province (Salton Sea—Sea of Cortez Trough) as the Imperial Valley (Figs. 1 and 2). This is a liquid-dominated field which began generating 75 MW of electric power in 1973. Early exploration efforts began in 1959 and a wealth of information has been collected by Mexican scientists and engineers. These include much data on the geological and geophysical characteristics of the area as well as chemical properties of the produced fluids. Geophysical and lithological logs, production data, wellhead temperatures and pressures, downhole temperatures and pressures are available for most (about 50) of the existing wells (Figs. 3 and 4).

1.1 HISTORY

The proximity of Cerro Prieto to the Mexican-American border and the level of activities currently under way and planned for the future make this geothermal field an ideal project for an international program of cooperative investigations. The idea for such a program to study the Cerro Prieto geothermal field was first discussed between Dr. Paul A. Witherspoon of the Lawrence Berkeley Laboratory (LBL), University of California, and Ing. Jorge Guiza Lambarri and Ing. Bernardo Domínguez Aguirre of the Comisión Federal de Electricidad of México (CFE), during the "Second United Nations Symposium on the Development and Use of Geothermal Resources" held in May 1975 in San Francisco, California.

Between June 1975 and early 1977, a number of meetings were held in Mexicali, Mexico City, and Washington, D. C. between representatives of CFE, the Consejo Nacional de Ciencia y Tecnología (CONACYT), LBL, and the United States Energy Research and Development Administration (ERDA, now a part of the U. S. Department of Energy, DOE). The purpose was to outline the different tasks that the proposed bilateral agreement would encompass. In April 1977, the final technical details were worked out at a meeting in Mexicali by personnel of the Coordinadora Ejecutiva de Cerro Prieto of CFE, headed by Ing. Héctor Alonso Espinosa, and by a group of representatives from LBL and ERDA. The official agreement was signed in Mexico City on July 21, 1977 by Ing. Manuel Moreno Torres, Subdirector General for CFE, and by Dr. Abraham S. Friedman, Scientific Attaché at that time in the U. S. Embassy in Mexico City, for ERDA. The complete text of the agreement is given in the appendix.

1.2 ORGANIZATION OF CFE PARTICIPATION

The coordinator of all Mexican activities to be carried out under the terms of this Mexican-American cooperative agreement is Ing. Héctor Alonso Espinosa from the Coordinadora Ejecutiva de Cerro Prieto of CFE. Ing. Alonso is being assisted by Ing. Alfredo Mañon Mercado, the Alternate Mexican Coordinator of the agreement.

CFE is actively involved in all tasks covered by the agreement (i.e., geologic, hydrogeologic, geophysical, geochemical, subsidence, and reservoir engineering studies). The Dirección General de Estudios del Territorio Nacional (DETENAL) is in charge of the first order leveling surveys. The Centro de Investigación Científica y Educación Superior de Ensenada (CICESE) is involved in passive seismic surveys at Cerro Prieto. The Instituto de Investigaciones Eléctricas (IIE) is performing feasibility studies on the possible reinjection of geothermal brines. CONACYT is assisting CFE in institutional aspects of this international project.

1.3 ORGANIZATION OF DOE PARTICIPATION

Participation in the agreement by the United States is being directed by the Division of Geothermal Energy (DGE) of DOE. At the present time, Dr. Allan J. Jelacic is the U. S. Coordinator of the agreement, recently replacing Dr. Leland L. Mink who was the first to serve in this capacity. The overall technical coordination of the U. S. activities is being carried out by LBL. Dr. Paul A. Witherspoon is the U. S. Alternate Coordinator, assisted by Dr. Marcelo J. Lippmann and Mr. Harold A. Wollenberg as Technical Coordinators of the agreement.

Various U. S. organizations are involved in this international project. DOE is funding and managing the overall U. S. involvement at Cerro Prieto. The Earth Sciences Division of LBL is active in most of the technical aspects of the agreement. The U. S. Geological Survey (USGS) is involved in geochemical surveys (Water Resources Division at Sacramento, and Topographic Division at Menlo Park). The University of California at Riverside (UCR, Institute of Geophysics and Planetary Physics) is performing mineralogic and petrologic studies on rock samples provided by CFE.

2.0 TECHNICAL PROGRAM

In this section the objectives, general scope, and programs of the various technical tasks are discussed.

2.1 GEOLOGY-HYDROGEOLOGY

Organizations involved: CFE, LBL, UCR

Objective: Define the geologic structure and hydrogeologic regime of the Cerro Prieto field.

General Scope

About 50 deep wells have been completed in the geothermal area. Geophysical well logs, lithologic logs, cuttings and cores are available from most of the wells. A large volume of data on shallow groundwater wells in the surrounding Mexicali Valley has been collected by the Secretaría de Agricultura y Recursos Hidráulicos. The analysis of the geophysical and lithologic logs may result in the correlation of various layers across the field and the determination of major geologic and sedimentary structures. The detailed mineralogic and petrologic analysis of cuttings and cores may indicate zones of different temperatures and areas of recharge or discharge of geothermal fluids. An open-file data bank has been established to aid further studies of this and similar geothermal fields.

This task is intimately related to the geophysical, reservoir engineering, and geochemical studies being carried out under the agreement.

Work Program

Geophysical well logs will be analyzed to establish different marker beds in the reservoir and caprock. Correlation of these layers between wells will be done using visual techniques and in some instances computer codes after the logs have been digitized. Partial results of these correlation studies have been presented in a report by Noble et al., (1977).

Petrological investigations of the cores and cuttings obtained from the CFE core collection will be made. These studies will include binocular-microscope and thin-section examination, X-ray diffraction determination of minerals, cathodoluminescence analyses, fluid inclusion studies, and microprobe analyses. Some results have been presented in a number of reports and papers by UCR authors (Elders et al., 1977; Elders et al., 1978; Hoagland and Elders, 1978; Olson and Elders, 1978). A preliminary geologic and hydrogeologic model of the Cerro Prieto area will be developed based on the newly-available information gathered during the first year of the agreement. Technical information on Cerro Prieto, provided mainly by CFE, is continuously being incorporated in an open-file data bank. An early report listing all available information was prepared by Lippmann et al., (1977).

As a better understanding of the geologic characteristics of the field is obtained, the effort in this task will be restricted to updating the models of the geothermal field. As new wells are completed, logs and samples gathered will be analyzed and integrated into the models of the area. These models might eventually be extended to cover larger regions of the Mexicali and Imperial Valleys.

2.2 GEOPHYSICS

Organizations involved: CFE, LBL, CICESE

Objective: Determine the dimensions and structure of the geothermal system. Monitor changes in the reservoir properties and seismicity during exploitation.

General Scope

Geophysical studies of the Cerro Prieto area began in the early sixties. Between 1961 and 1963 gravimetric and refraction seismic surveys were made. In 1965, 50 shallow wells were drilled for heat flow determinations. An aeromagnetic study of the area was completed in 1972. The first electrical resistivity surveys at and around the geothermal field were made in 1972 and 1975. The information collected from these earlier studies are available and will be reinterpreted in light of results of new surveys and wells. Resistivity, self-potential, magnetotelluric, gravimetric, precise-gravity, and passive-seismic surveys will be made and interpreted to define the geologic structure of the field. Periodic resurveying of the area (possibly on an annual basis) may determine changes in some field characteristics which could be related to geothermal fluid production. These variations may then be correlated with production rates and surface subsidence measurements. The use of different geophysical techniques will permit evaluation of the various methods for studying liquid-dominated geothermal systems under large-scale fluid production.

Work Program

Interpretation of some of the available Schlumberger resistivity studies using computer models is in progress (Wilt and Goldstein, 1978). Resistivity (Schlumberger and dipole-dipole arrays) and magnetic surveys will be run along several west-east trending lines traversing the geothermal field and surrounding areas (Razo et al., 1978). Self-potential and magnetotelluric surveys will be carried out to evaluate these methods in studying producing liquid-dominated systems (Corwin et al., 1978). Seismometer arrays for passive seismic studies have been temporarily installed in the field to complement the data being recorded at permanent stations located near the field (Reyes et al., 1978). Precise gravity measurements have been carried out at specially constructed, permanent stations within and outside the producing area. Based on the data collected in this and other tasks, preliminary geologic models of the field will be constructed.

As in the geology-hydrogeology studies, later on the main effort will be in updating the models of the field and in studying areas not covered before. The resistivity and precise gravity stations will be reoccupied periodically. The permanent seismic stations will be monitored on a continuous basis.

2.3 RESERVOIR ENGINEERING

Organizations involved: CFE, LBL

Objective: Determine the size, geometry, and physical characteristics of the reservoir using well testing and laboratory techniques.

General Scope

Production data (flow rate, wellhead temperature, pressure and fluid enthalpy) as well as downhole temperature and pressure logs are available for most of the wells. Interpretation of well interference tests and two-rate flow tests will disclose some of the hydraulic properties and flow boundaries of the producing reservoir. A number of physical properties will be measured on core samples in the laboratory under elevated temperature and pressure conditions. Heat and mass transfer in the reservoir will be numerically modeled to simulate the behavior of the geothermal field under large-scale production and long-term well tests.

Work Program

Computer models will be used to match the water level variations in an observation well (M-6) in response to fluid extraction in the main area of the field. Long-term well interference tests will be carried out in zones adjacent to the present production area as new wells are being developed. Short term two-rate flow tests will be made in some of the producing wells. Permeability, thermal conductivity, shear and compressional wave velocities will be measured in cores under high temperature and pressure conditions. Reservoir behavior will be simulated using numerical models. Results of these models will be compared with field data to validate the models and their ability to predict future reservoir behavior.

2.4 REINJECTION

Organizations involved: CFE, IIE, LBL

Objective: Establish the feasibility of reinjecting geothermal brines into the reservoir.

General Scope

At the present time, the electric power production of 75 MW requires disposal of about 1,700 metric tons of hot brine in an evaporation pond. Concurrently, reservoir pressure is decreasing. The problems of brine disposal and

reservoir pressure drops will increase as new power plants are put on line. The feasibility of reinjecting some or all of the brine to recharge the geothermal reservoir will be studied. These studies will analyze future temperatures of the produced fluids, reservoir pressures, possible ground subsidence, and chemical reactions between the reinjected brine and both the native fluids and reservoir rocks.

Work Program

Computer simulation studies will be made using a simplified model of the Cerro Prieto system to analyze the temperature and pressure variations resulting from injecting colder waters into the reservoir (Tsang et al., 1978). An annotated bibliography on reinjection will be completed (Mercado et al., 1978). Studies on water incompatibility, colloidal silica, and brine modification will be initiated. Additional computer simulations will be made, possibly including chemical reactions and computation of ground surface deformations which may accompany fluid injection. A field test involving a deep well may be started in the latter part of 1979.

2.5 GEOCHEMISTRY

Organizations involved: CFE, USGS, UCR, LBL

Objective: Determine the age and origin of the geothermal fluids, estimate possible recharge sources and routes, and establish the extent and type of rock-fluid interactions.

General Scope

Standard chemical analyses of geothermal fluids have been made since the first exploration wells were drilled in 1959. Between 1965 and 1966 studies of the geochemistry of springs and fumaroles in the area were accomplished. In addition the Secretaría de Agricultura y Recursos Hidráulicos is continuously collecting data on the surface and shallow groundwaters of the Mexicali Valley.

A recompilation and analysis of available fluid chemistry data may delineate zones of different chemical characteristics within the field and indicate some of the physical phenomena occurring in the geothermal reservoir. Special sampling techniques will be used to collect geothermal fluids for isotope analysis. Stable isotope ratio studies in minerals will disclose the extent and type of reactions occurring between the reservoir fluids and rocks.

Work Program

A preliminary geochemical model of the field will be developed based on the wealth of chemical analyses available from Cerro Prieto (Mañon et al., 1977). Geothermal waters, geothermal gases, shallow groundwater and surface waters will be analyzed for trace elements and isotopes to establish some of the physical and chemical processes taking place and to determine the age and

sources of the geothermal fluids (Truesdell and Mañon, 1978). Oxygen and carbon isotope ratios of calcite from cuttings and cores will be determined to estimate temperature of reaction and water-rock interactions in the geothermal system (Elders et al., 1977; Olson and Elders, 1978). The results will be incorporated into a geochemical model of the geothermal reservoir.

2.6 SUBSIDENCE

Organizations involved: DETENAL, USGS

Objectives: Determine local horizontal and vertical ground surface deformations in the area. Distinguish deformations resulting from the extraction of geothermal fluids from those related to other causes.

General Scope

The Salton Sea—Sea of Cortez Trough, where the Cerro Prieto field is located, is a tectonically active area. Surveys already completed in the Imperial Valley in the United States indicate natural vertical ground deformations in the range of a few centimeters per year. Localized horizontal tectonic movements of a few millimeters per year have also been measured (Lofgren, 1974). Periodic monitoring of regional and local survey nets may permit differentiation between ground movements at Cerro Prieto related to the production of geothermal fluids from ground movements associated with tectonic activity.

Work Program

To obtain base-line data on vertical deformations, a network of first-order leveling control has been established and surveyed. This net ties the Cerro Prieto area to bench marks at the international border. The base-line data for the horizontal components of ground movement will be obtained from a regional trilateration and a local network of precise horizontal control. The nets have been established and initially surveyed. The regional network ties with that in the Imperial Valley and continues considerably south of the Cerro Prieto system. The local nets cover the area surrounding the production field. The three survey nets will be reoccupied about a year after base-line data are obtained, and the networks will be surveyed periodically thereafter to detect crustal deformations.

2.7 CONFERENCES

Organizations involved: CFE, DOE

Objective: Make available to the international geothermal community the results of this multidisciplinary project.

General Scope

In addition to the technical reports, which will be issued in Spanish and English, annual conferences open to all interested parties will be organized.

These meetings will allow an open discussion and exchange of ideas between those active in the project and other geothermal specialists. Proceedings will be issued following the conferences. The meetings will be held alternatively in California and Baja California, Mexico.

Work Program

The "First Symposium of the Cerro Prieto Geothermal Field" will be held in San Diego, California, September 20-22, 1978. A trip to the Cerro Prieto field will follow on September 23. The second CFE/DOE Cerro Prieto conference is tentatively planned for September 1979 in Mexicali, Baja California. Annual conferences on Cerro Prieto will continue over the life of the Mexican-American cooperative program. Presently, the agreement will terminate in July 1982, although it may be renewed and continued by mutual consent between CFE and DOE.

3.0 SUMMARY

The Mexican-American cooperative program of investigations at Cerro Prieto is one of the first international efforts to develop a comprehensive analysis of a liquid-dominated geothermal system. This program was made possible through the execution of an official agreement on July 21, 1977, in Mexico City between the Comisión Federal de Electricidad (CFE) and the U. S. Energy and Development Administration, which is now part of the U. S. Department of Energy (DOE).

Early exploration efforts at Cerro Prieto were started in 1959; and the first generation of power, 75 MWe, began in 1973. A wealth of information on geological, geophysical, and chemical data has been collected by Mexican scientists and engineers. The proximity of Cerro Prieto to the Mexican-American border and the level of activities currently under way and planned for the future make this geothermal field an ideal project for cooperative investigations.

The program involves a series of field and laboratory studies on geology-hydrogeology, geophysics, geochemistry, reservoir engineering, reinjection, and subsidence at Cerro Prieto. A number of different organizations are participating, with the Mexican activities being coordinated by CFE and the U. S. activities being coordinated by DOE. Results will be communicated in the form of technical reports, workshops, and scientific meetings.

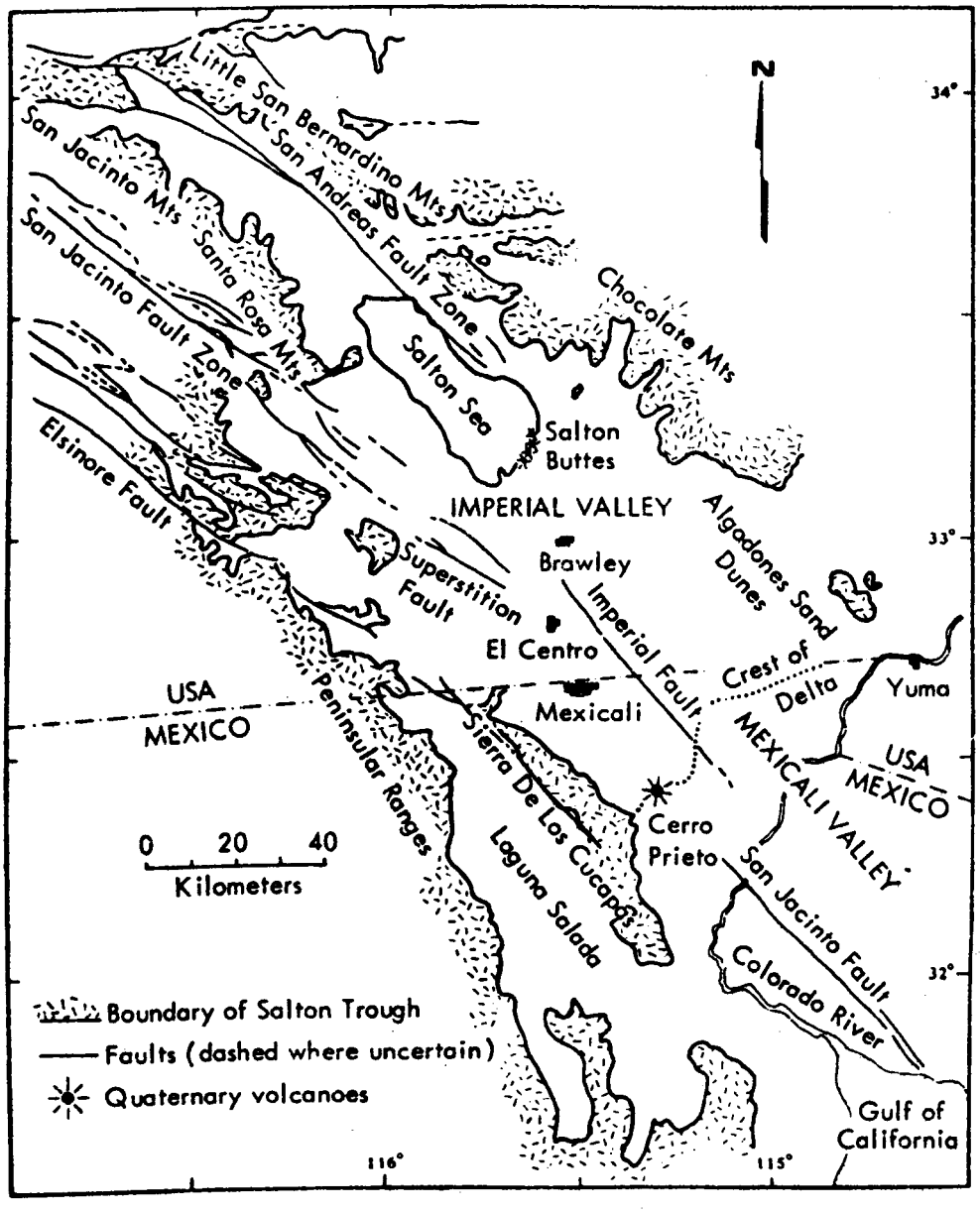

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Fig. 1 Salton Trough (or Salton-Sea—Sea of Cortez Trough) showing Imperial and Mexicali Valleys (from Palmer et al., 1975).

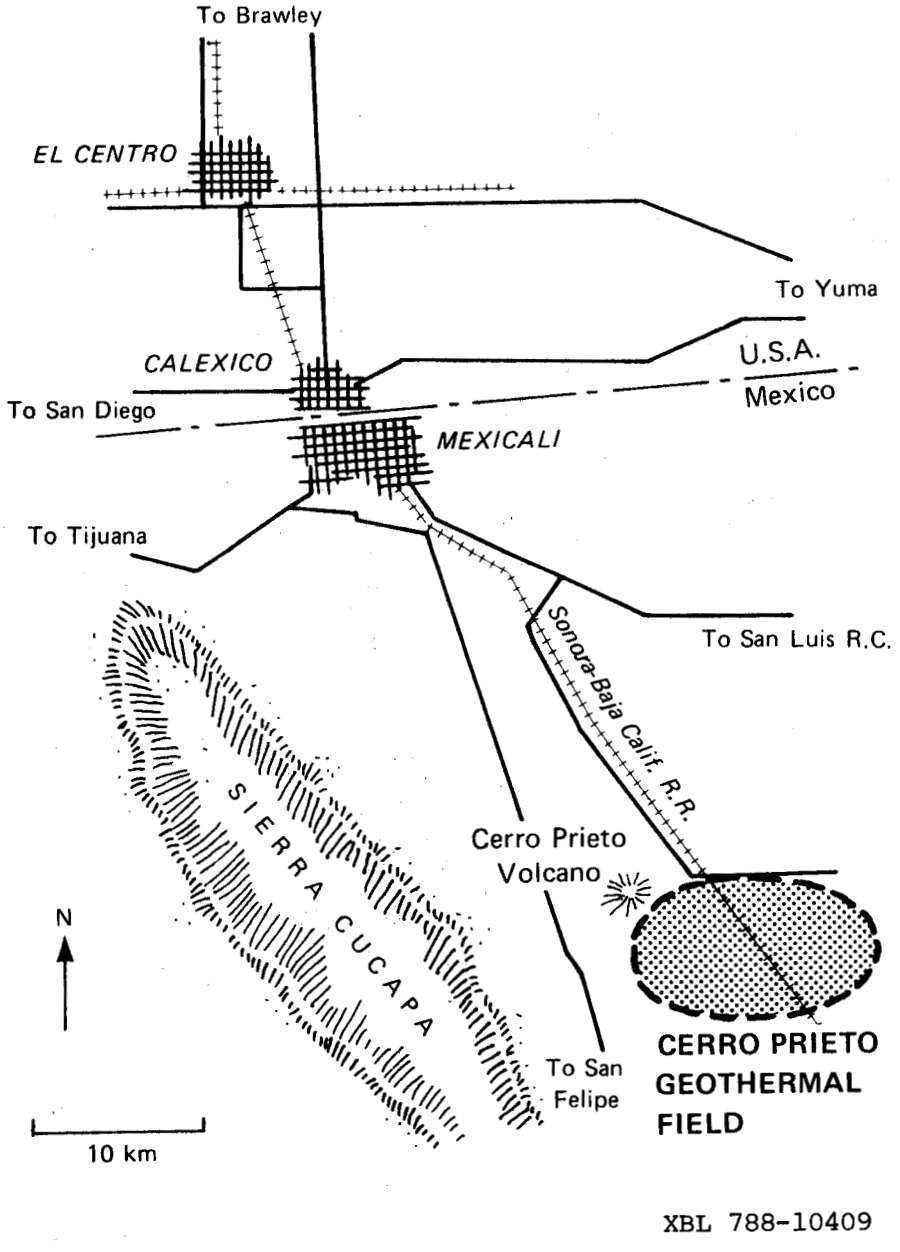

Fig. 2. Location map of the Cerro Prieto geothermal field.

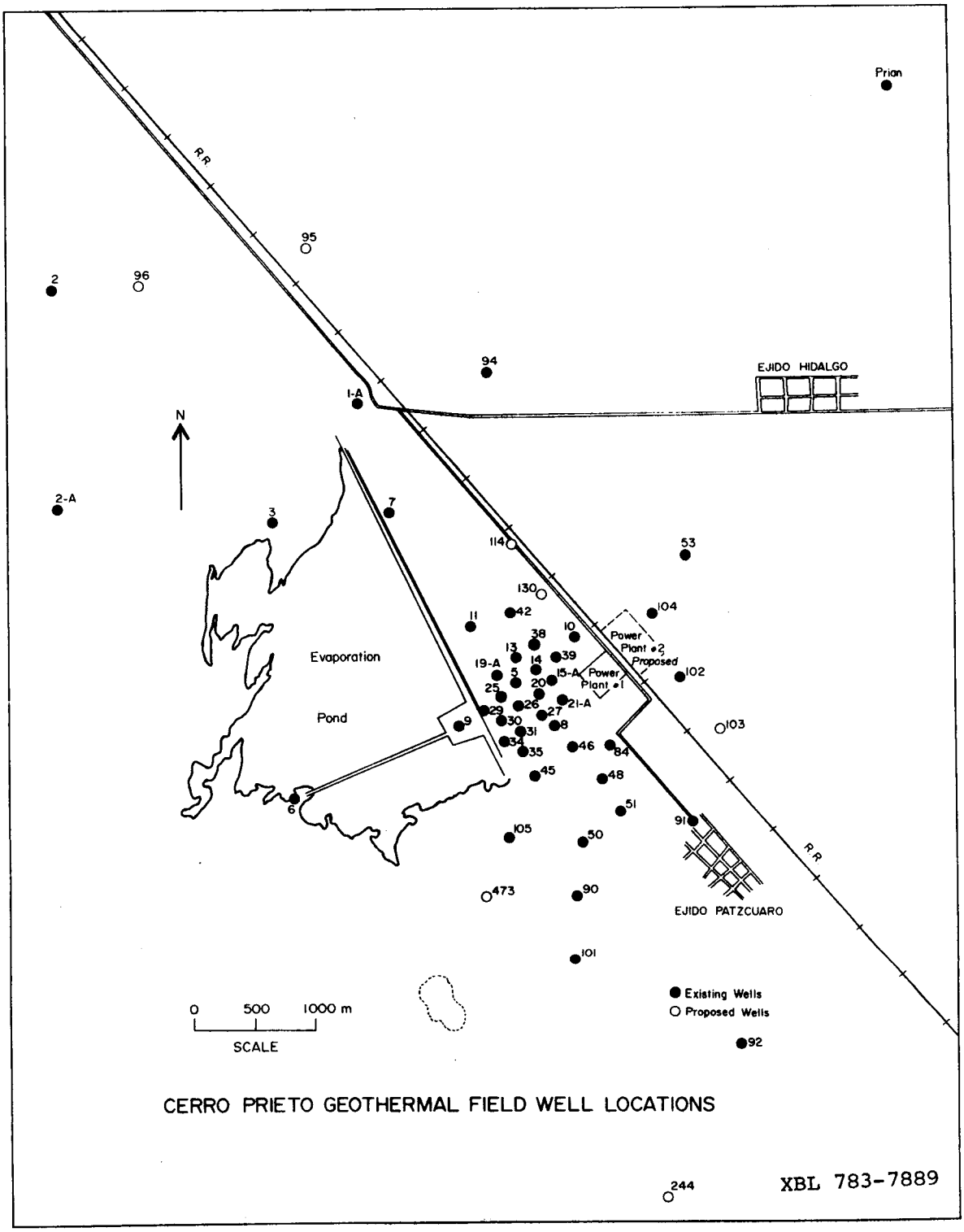

Fig. 3 Cerro Prieto geothermal field well locations (as of March 1978).

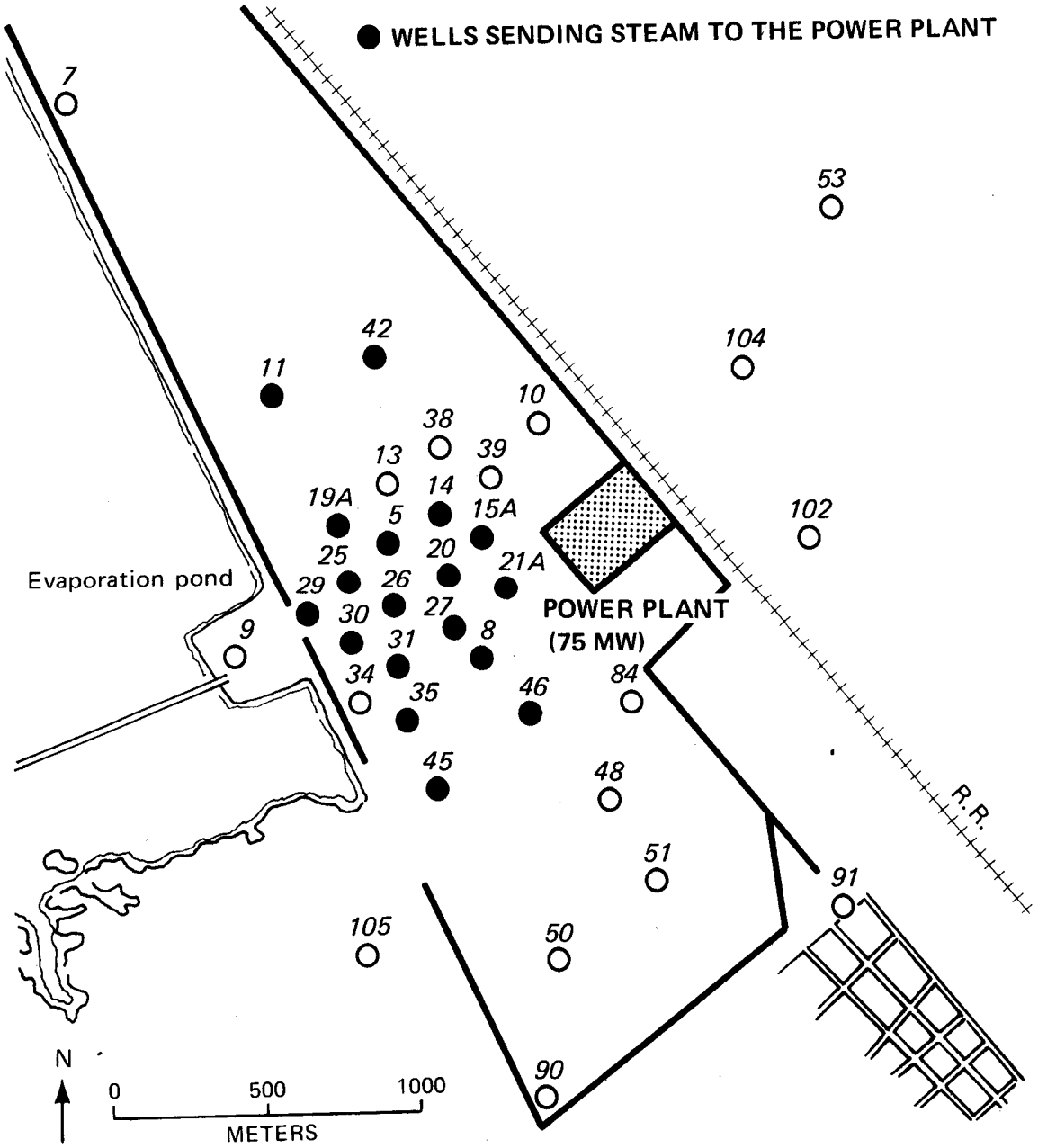

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Fig. 4 Location of wells in the main part of the Cerro Prieto geothermal field (as of March 1978).

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5.0 APPENDIX

AGREEMENT BETWEEN THE

COMISION FEDERAL DE ELECTRICIDAD OF THE UNITED MEXICAN STATES

AND THE

U.S.A. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

The Comisión Federal de Electricidad (hereinafter referred to as CFE) of the United Mexican States (hereinafter referred to as Mexico) and the United States of America's Energy Research and Development Administration (hereinafter referred to as ERDA).

Desiring to promote the closest collaboration between the United States of America and Mexico in the field of geothermal energy research and development, on the basis of mutual benefit between the Governments of Mexico and the United States of America, and

Recognizing that technological cooperation in research and development in the area of geothermal energy will benefit their respective countries, and in accordance with the principles set forth in the Science and Technology Agreement that was signed between both Countries on June 15, 1972, and taking into account the July 20, 1976 decision by the U.S./Mexico Mixed Commission on cooperation in Science and Technology to include geothermal energy as an area of cooperative activity, and the past multilateral

cooperation in the same technical area under the sponsorship of the Committee on the Challenges of Modern Society of NATO,

Have agreed as follows:

ARTICLE I

OBJECTIVES

A. CFE and ERDA (hereinafter referred to as the Parties) shall make every effort to pursue an intensive program of cooperation for research, development and demonstration of applications of geothermal energy, centered on the Cerro Prieto Geothermal Field. These studies may include:

(1) Analysis of geologic and hydrogeologic setting

(2) Geophysical studies

(3) Core sample and well logging

(4) Isotope studies of geothermal, shallow groundwater and surface waters

(5) New methods of pressure measurement

(6) Subsidence measurements

(7) Monitoring reservoir behavior

(8) Modelling reservoir behavior

(9) Reinjection of waste water

(10) Other related fields of mutual interest to be agreed upon

B. The major objectives shall be to develop a thorough understanding of the nature and magnitude of this energy resource, to investigate how the geothermal source can best be exploited consistent with the long range needs of the Mexican energy program, and to determine the impact on the reservoir's subsurface environment.

C. Cooperation under this Agreement may include, but not be limited to, the following forms:

(1) Exchange of information on scientific and technical developments, activities, and practices concerning geothermal energy development;

(2) Meetings to be held alternately in Mexico and in the United States or as mutually agreed to discuss and exchange information on scientific and technological developments and to identify specific research and development Tasks agreed to by both Parties;

(3) Visits and exchanges of scientists, technicians or other experts, and the conduct of workshops as mutually agreed upon;

(4) Exchange of project and experimental plans for review and comment and, if practicable, the reviewing side may recommend add-on

experiments;

(5) Conduct of joint projects and programs, or separate but complementary projects or programs; and

(6) Joint funding of cooperative projects for agreed purposes under this Agreement.

It is anticipated that agencies, institutions and individuals other than the Parties mentioned above (CFE and ERDA) will participate in the activities to be undertaken under the auspices of this Agreement. Their participation through the Parties shall be subject to the full terms and conditions of this Agreement.

ARTICLE II

TASKS

Specific obligations and conditions for the realization of specific mutually agreed research and development projects and programs as specified in Article I shall be set forth in Tasks attached in annexes to this Agreement. Such Tasks shall be concluded in accordance with this Agreement and the applicable laws, regulations, executive orders, and license requirements of the respective Governments.

ARTICLE III

COORDINATORS

The Parties shall each designate a Coordinator who shall be responsible for the overall supervision of this Agreement and the Tasks thereunder, and each Party shall also designate an alternate Coordinator to represent the Party if the Coordinator is unable to do so. Each Party shall inform the other Party in writing of all designations under this paragraph. The Coordinators may designate such persons and establish such subsidiary bodies and rules of procedures as are required for the proper functioning of the Coordinators. The Coordinators or their designees shall periodically meet as they deem necessary to review the progress of the cooperative activities undertaken pursuant to this Agreement. Progress reports shall be issued by the Coordinators at six month intervals or as mutually agreed.

ARTICLE IV

FINANCE

In carrying out the various cooperative activities the Parties shall be subject to the appropriation of funds by the appropriate governmental authority and to

the laws and regulations applicable to the Parties including, but not limited to, laws establishing prohibitions upon payment of commission, percentages, brokerage or contingent fees to persons retained to solicit government contracts, and upon any share of such contracts accruing to governmental officials. Each party shall bear the costs of its participation in the activities under this Agreement as set forth in the tasks attached hereto.

ARTICLE V

INFORMATION EXCHANGE

A. The Parties will exchange, as agreed on a mutually beneficial basis, scientific and technical information documents, and results of research and development related to work carried out under this Agreement. Such information will be limited to that which they have the right to disclose, either in their possession or available to them.

B. Seminar proceedings and reports of joint programs carried out under this Agreement will be published as joint publications, as mutually agreed to by both Parties, in both the English and Spanish languages.

C. Both Parties agree that information developed or exchanged under this Agreement should be given wide

distribution. Such information, except as noted in D and E below, may be made available to the public by either Party through customary channels and in accordance with normal procedures of the Parties.

D. It is recognized by both Parties that in the process of exchanging information, or in the process of other cooperation, the Parties may provide to each other "industrial property of a proprietary nature." Such property, including trade secrets, inventions, patent information, and know-how, made available hereunder, but acquired by either Party prior to, or outside, the course of these activities, and which bears a restrictive designation, shall be respected by the receiving Party and shall not be used for commercial purposes or made public without the consent of the transmitting Party. Such property is defined as:

(1) Of a type customarily held in confidence by commercial firms;

(2) Not generally known or publicly available from other sources;

(3) Not having been made available previously by the transmitting Party or others without an agreement concerning its confidentiality; and

(4) Not already in the possession of the receiving Party or its contractors.

E. Recognizing that "industrial property of a proprietary nature," as defined above, may be necessary for the conduct of a specific cooperative project or may be included in an exchange of information, such property shall be used only in the furtherance of geothermal programs in the receiving country. Its dissemination will, unless otherwise mutually agreed, be limited as follows:

(1) To persons within or employed by the receiving Party; and

(2) To prime or subcontractors of the receiving Party for use only within the territory of the receiving Party and within the framework of its contract(s) with the respective Party engaged in work relating to the subject matter of the information so disseminated; provided that the information disseminated to any person

under subparagraphs (1) and (2) above shall bear a marking restricting dissemination outside the recipients organization. It shall be the responsibility of each Party supplying proprietary information to identify the information as such and to ensure it is appropriately marked. Each Party will use its best efforts to ensure that the dissemination of proprietary data received under this Agreement is controlled as prescribed herein.

ARTICLE VI

INFORMATION SUBJECT TO PATENTS

The information exchanged under this Agreement shall be subject to the patent provisions in Article VIII.

ARTICLE VII

RESPONSIBILITY

The application or use of any information exchanged or transferred between the Parties under this Agreement shall be the responsibility of the Party receiving it, and the transmitting Party does not warrant the suitability of such information for any particular use or application.

ARTICLE VIII

PATENTS

A. With respect to any invention or discovery made or conceived in the course of or under this Agreement:

1. If made or conceived by personnel of one Party (the Assigning Party) or its contractors while assigned to the other Party (Recipient Party) or its contractors, in connection with exchanges of scientists, engineers, and other specialists;

(a) The Recipient Party will acquire all right, title and interest in or to any such invention, discovery, patent application or patent in its own country and in third countries, subject to a non-exclusive, irrevocable, royalty-free license to the Assigning Party, with the right to grant sublicenses, under any such invention, discovery, patent application or patent.

(b) The Assigning Party will acquire all right, title, and interest in or to any such invention, discovery, patent application, or patent in its own country, subject to a non-exclusive, irrevocable royalty-free license to the Recipient Party, with the right to grant sublicenses, under any such invention, discovery, patent application or patent.

2. If made or conceived by a Party or its contractors as a direct result of employing information which has been communicated to it under this Agreement by the other Party or its contractors or communicated during seminars or other joint meetings, the Party making the inventions will acquire all right, title and interest in and to any such invention, discovery, patent application or patent in all countries, subject to a grant to the other Party of a royalty-free, non-exclusive, irrevocable license with the right to grant sublicenses, in and to any such invention discovery, patent application, or patent, in all countries.

3. With regard to other specific forms of cooperation, including exchanges of materials, instruments, and equipment for special joint research projects, the Parties shall provide for appropriate distribution of rights to inventions resulting from such cooperation. In general, however, each Party should normally determine the rights to such inventions in its own country, with a non-exclusive, irrevocable,

royalty-free license to the other Party, and the rights to such inventions in other countries should be agreed upon by the Parties on an equitable basis.

B. Neither Party shall discriminate against citizens of the country of the other Party with respect to granting any license or sublicense under any invention pursuant to paragraph 1 above. It is understood that the licensing policies and practices of each Party can be affected because of the rights of both Parties to grant licenses within a single jurisdiction. Accordingly, either Party may request, in regard to a single invention or class of inventions, that the Parties consult in an effort to lessen or eliminate any detrimental effect that the parallel licensing authorities may have on the policies and practices of the Parties.

C. The Parties shall provide all necessary cooperation from its inventors to carry out the provisions of paragraphs A and B above.

D. Each Party shall assume the responsibility to pay awards or compensation required to be paid to its own nationals according to its own laws.

ARTICLE IX

LIABILITY

Both Parties agree that the following provisions shall apply concerning compensations for damages incurred during the conduct of joint projects.

A. First and second Party damages.

(1) Each Party shall alone be responsible for payment or compensation for damages suffered by its staff, regardless of where the damages have been incurred and shall not bring suit or lodge any other claims against the other Party for damages to its property except as noted in paragraphs A (2) and (3).

(2) If the damage suffered by the staff of one of the Parties is due to the gross negligence or intentional misconduct of the other Party, the latter shall reimburse the former an agreed sum of monies which the former would be obliged to pay to the person or persons suffering the damages.

(3) If damages to the property of one party are due to the gross negligence or

intentional misconduct of the staff of the other Party, the latter shall compensate the former for the damages suffered.

B. Third Party damages.

(1) Defective equipment.

Damages caused to the staff or property of a third Party by defective equipment of a Party shall be compensated for by the Party to which the equipment belongs, except as noted in paragraph B (3).

(2) By staff.

Damages caused to the staff or property of a third Party by the staff of a Party shall be compensated for by such Party regardless in whose territory the damages occurred, except as noted in paragraph B (3).

(3) Gross negligence or intentional misconduct.

If damages referred to in paragraph B (1) and B (2) were due to the gross negligence or intentional misconduct of the staff of a Party, that Party shall bear the

financial responsibility in regard to the third Party.

(4) Damage by the third Party.

In the event of damage of any kind caused by a third Party to the staff or property of one of the Parties, each of these shall render its aid in the corroboration of claims on the third Party.

(5) Resolution of questions.

The Party on whose territory the damage caused by a third Party was incurred shall in consultation with the other Party, take upon itself the resolution, with the third Party, of all questions connected with the determination of the causes, extent and necessity for compensation for damages incurred. Any such resolution shall have the concurrence of the other Party. After determining the extent of the damages, both Parties shall mutually consult and reach agreement on questions relating to compensation for damages incurred.

C. In the event of any dispute between the two Parties, a Committee shall be appointed by the Parties, with equal representation, the conclusion of the Committee shall be presented to ERDA and CFE who will review the conclusions and arrive at a mutual agreement concerning final disposition.

D. The foregoing provisions of this Article shall have no applicability to damages caused by a nuclear incident, as defined by the laws of the Parties. Compensation for damage caused by such nuclear incident shall be in accordance with the laws of the Parties.

E. Definitions.

(1) "Staff" of a Party means the employees of the Party, its contractors and subcontractors performing services under this Agreement, and employees of these contractors and subcontractors performing services under this agreement.

(2) "Equipment" or "property" of a Party means the equipment or property owned by that Party, or by the contractors or subcontractors of that Party who perform services in connection with joint projects under this Agreement.

ARTICLE X

OBLIGATIONS

A. In fulfillment of this Agreement, each Party shall take measures to facilitate the entry and the departure of scientists and technicians and the equipment from the country of the other Party which, previously selected with the consent of both Parties is, by specific agreement, going to be utilized in any joint activity by project personnel.

B. Each Party shall provide assistance, when necessary, to obtain clearance in matters which include, but are not necessarily limited to, customs, drivers permits, work permits or the equivalent, exit and entry visas, and other services that may involve other agencies of the respective Governments.

ARTICLE XI

DIRECT CONTACTS AND COOPERATION

Both Parties shall, as appropriate, encourage the establishment and development of direct contacts and cooperation between agencies, organizations, and firms of both countries with respect to technological cooperation in research and development in the area of geothermal energy.

ARTICLE XII

ARBITRATIONS

Any dispute between the Parties concerning the interpretation or the application of this Agreement, which is not settled by negotiation or other agreed mode of settlement shall be referred to a Tribunal of three arbitrators to be chosen by the Parties who shall also choose a Chairman of the Tribunal. Should the Parties concerned fail to agree upon the composition of the Tribunal or the selection of its Chairman, the President of the International Court of Justice shall, at the request of any of the Parties concerned, exercise those responsibilities. The Tribunal shall decide any such dispute by reference to the terms of the Agreement and any applicable laws and regulations, and its decision

on a question of fact shall be final and binding on the Parties.

ARTICLE XIII

ADDITIONAL ARRANGEMENTS

Nothing in this Agreement shall be construed to prejudice other arrangements or future arrangements for cooperation between the Parties.

ARTICLE XIV

TERMINATION, CANCELLATION, EXPIRATION, OR AMENDMENTS

The termination, cancellation, expiration, or amendment of this Agreement shall not automatically affect the carrying out of any project or program undertaken in accordance with this Agreement and not fully executed at the time. This Agreement may be amended at any time by the Parties. Such amendments shall come into force in a manner to be determined by the Parties.

ARTICLE XV

FINAL PROVISIONS

A. This Agreement shall enter into force on the latter date of signature by a Party and shall remain

in force for a period of five (5) years. This Agreement may be extended by mutual agreement of the Parties for a further specified period.

B. This Agreement may be terminated at any time at the discretion of either party, upon six (6) months advance notification in writing by the Party seeking to terminate the Agreement. Such termination shall be without prejudice to the rights which may have accrued under this Agreement to either Party up to the date of such termination.

FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

ABRAHAM S. FRIEDMAN
Scientific Representative

FOR THE COMISION FEDERAL DE ELECTRICIDAD

ING. MANUEL MORENO TORRES
Subdirector General

México, D. F.

July 21, 1977

ANNEX A

FUNDING

Each Party shall bear the costs of its responsibilities assigned in the following tasks. In the event ERDA requests any additional surveys and special work in addition to the studies specified in the tasks, ERDA shall bear the costs of such additional work.

PATENTS

As required by Paragraph A(3) of Article VIII of the Agreement, the following distribution of rights to inventions or discoveries made or conceived in the course of or under this Annex A shall be applicable.

1. Rights to such inventions and discoveries in the United States and Mexico shall be as set forth in Paragraph A(3) of Article VIII.

2. Rights to such inventions and discoveries in other countries shall be jointly owned by the United States and Mexico.

TASK 1: GEOLOGY AND HYDROGEOLOGY

1. Objectives. The objectives of this Task are to collect, analyze, and evaluate the available geological, geochemical and reservoir information for definition of the geothermal system's geologic structure.

2. Research and Time Schedule

1977. Relevant CFE data will be translated and edited by ERDA for placement in open-file reports available to the geothermal community. The present program of sample, core and log analysis and interpretation will be expanded to include advanced analytical techniques for sample characterization, supplemental well coring and logging for additional geological information will be planned. The geologic and hydrogeologic conceptual modeling of the Cerro Prieto Geothermal System will be initiated, based on presently available information. These models will be continuously refined as additional data is acquired.

1978. Work will focus on the continued refinement of the geologic model of the geothermal system based on the integration of additional well logs, cores and geoscience information.

1979. Geologic and hydrogeologic modeling of the Cerro Prieto System will be completed to the extent possible based on the available data. These models will be validated through field checking with new well data as it is acquired.

3. Responsibilities. The Parties will undertake the following responsibilities:

A. ERDA

(1) In consultation with CFE, ERDA shall plan an expanded program for sample, core and geophysical log acquisition and analysis. ERDA shall provide financial support for additional coring and logging which is requested by ERDA and not part of the CFE Field Program.

(2) ERDA shall undertake the modeling of the reservoir based on data provided by CFE.

(3) ERDA shall publish a reservoir case study for the Cerro Prieto Field.

B. CFE

(1) CFE shall provide assistance to ERDA, as specified in Paragraph A(1) above, for sample, core and geophysical log acquisition and analysis. CFE shall provide financial support for the coring and logging routinely required for field development and exploration.

(2) CFE shall provide the data necessary for ERDA to execute its responsibilities as set forth in Paragraph B(1) above.

(3) CFE shall make available to ERDA copies of geophysical logs, drilling reports, samples and cores for wells drilled prior to the execution of this Agreement, as well as those drilled during the term of this Agreement.

(4) CFE shall participate in the data interpretation and in the development of models of the field.

TASK 2: GEOPHYSICS

1. Objectives. The objectives of this Task are to define the dimensions and gross structure of the field in order to better understand the functioning of the Geothermal System and to monitor reservoir behavior during production through surface geophysical techniques.

2. Research and Time Schedule.

1977. The Geophysical Program will be planned and coordinated with persons involved in the surface surveys as specified in Task 6. Geophysical studies, as set forth in subtasks 2A, 2E and 2F below, will be imple-

mented first. The remaining subtasks (2B, 2C, 2D) will be implemented in the Winter Field Season of 1977-78. The subtasks are as follows:

SUBTASK 2.A: PASSIVE SEISMIC MONITORING: Determine the lateral dimensions of the reservoir by means of the lateral variations in P and S wave velocity. Determine the locations and relative motions of active faults in the reservoir area.

SUBTASK 2.B; MAGNETOTELLURICS: Determine the basement depth and configuration by utilizing deep electrical sounding techniques.

SUBTASK 2.C; SELF-POTENTIAL: Conduct self-potential survey over the Cerro Prieto Field to determine whether an anomaly exists coincident with the reservoir.

SUBTASK 2.D; DIPOLE - DIPOLE RESISTIVITY: Conduct a wide - aperture - dipole - dipole survey on one long line crossing the field to measure resistivity features associated with the reservoir and basement structure.

SUBTASK 2.E; PRECISION GRAVITY: Conduct tidal monitoring and a precise gravity survey to detect mass changes that may be associated with reservoir depletion and the effects of future waste water reinjection.

SUBTASK 2.F; GRAVITY MODELING: Estimate the basement

configuration of the Mexicali Valley by means of computer modeling of existing Bouger gravity data calibrated with density measurements on core samples from a hole drilled to basement rock.

1978. Repetitive measurements will be necessary for some of the subtasks in order to measure possible changes in the character of the reservoir.

1979. Additional and repetitive field surveys will continue and all information will be gathered into a model of the reservoir and the geologic structure.

3. Responsibilities.

A. ERDA

(1) ERDA and CFE will jointly plan the geophysical surveys as aforementioned in the subtasks.

(2) ERDA will have lead responsibility for conducting these field geophysical surveys and data analysis.

(3) ERDA will provide financial support for the field geophysical surveys and data analysis, as well as vehicles and geophysical equipment.

B. CFE

(1) CFE will have joint responsibility for the planning of the geophysical surveys as specified in the subtasks and Paragraph A(1) above.

(2) CFE will provide at least one person per crew or vehicle to assist ERDA in the field surveys.

(3) CFE will participate in the geophysical data analysis.

TASK 3: RESERVOIR ENGINEERING

1. Objectives. The objectives of this task are to define the size, geometry, physical characteristics, fluid capacity, recharge capability, production ability and energy longevity of the reservoir.

2. Research and Time Schedule.

1977. A team composed of people from CFE and ERDA will plan and begin conducting well production and interference tests and static pressure-temperature tests. The major subtasks during the first year are as follows:
SUBTASK 3.A; Plan interference tests using existing Cerro Prieto wells to determine the formation parameters, inhomogeneities, faults and flow barriers, and possible fracture characteristics.

SUBTASK 3.B; Carry out interference tests using accurate measuring devices on existing Cerro Prieto wells.
SUBTASK 3.C; Plan well testing to determine the formation properties associated with the wells used for the controlled injection experiments, and the parameter modifications which might occur during the injection experiments.
SUBTASK 3.D; Carry out initial tests for the formation parameters associated with the controlled injection experiment.
SUBTASK 3.E; Plan a program of continuous monitoring of wellhead temperature, pressure, flow rates and enthalpy on all Cerro Prieto production wells.

1978. Analyze reservoir data and correlate with ongoing Imperial Valley Programs. Conduct tests in conjunction with the controlled reinjection experiment when scheduled. Continue interference tests (Subtask 3.B).

1979. Continue to correlate and apply obtained information to developing Imperial Valley reservoirs. Carry out reservoir tests employing planned CFE observation and production wells.

3. Responsibilities.

A. ERDA

(1) ERDA and CFE will jointly plan the reservoir tests as specified in the Subtasks.

(2) ERDA will have lead responsibility for the implementation of the reservoir measurements conducted pursuant to the schedule.

(3) ERDA will provide downhole and surface equipment necessary to conduct the tests.

B. CFE

(1) CFE will have joint responsibility for the reservoir tests as specified in the Subtasks and Paragraph A(1) above.

(2) CFE will provide access to the geothermal wells during all tests set forth in the Subtasks.

(3) CFE will participate in the analysis of reservoir engineering data.

TASK 4: REINJECTION

1. Objectives. The objectives of this task are to verify analytical models of reservoir behavior under exploitation and reinjection, and analyze hydrodynamic, thermodynamic and subsidence effects. The Cerro Prieto Field will be monitored under controlled conditions.

2. Research and Time Schedule.

1978. Preliminary planning for deep injection wells will be completed. The major Subtasks during the first year are as follows:

SUBTASK 4.A; Plan deep injection experiments in the Cerro Prieto Field to determine hydrodynamic and thermal flow patterns using tracers and other techniques.

SUBTASK 4.B; Plan chemistry experiments associated with scaling and reduction of in situ porosity and permeability.

SUBTASK 4.C; Calculate heat and fluid flows due to re-injection in the Cerro Prieto Field using computer models.

3. Responsibilities.

A. ERDA

(1) ERDA will assist CFE in planning the injection program.

(2) ERDA will assume lead responsibility for the preparation of computer models describing the perturbation of heat and fluid flow resulting from injection.

B. CFE

(1) CFE will plan the injection program with the assistance of ERDA as specified in Paragraph A(1).

(2) CFE will assume lead responsibility for the implementation of the injection experiments.

(3) CFE will participate in the interpretation of reinjection experimental data and in the development of models of the field.

TASK 5: ISOTOPIC ANALYSIS

1. Objectives. The objectives of this task are to determine the origin of the geothermal fluids and the possible recharge sources and rates. Geothermal fluids, round and surface waters, will be analyzed and previous Cerro Prieto studies on fluid chemistry will be reviewed.

2. Research and Time Schedule.

1977. Existing data on fluid chemistries of the Cerro Prieto Field will be reviewed and a sampling program encompassing geothermal fluids, surface waters and ground water, will be planned. The major Subtasks for the first year are as follows:

SUBTASK 5.A; Design a program of isotopic studies in cooperation with the Mexican specialists.

SUBTASK 5.B; Collect hot and cold surface waters, waters and gases from well discharges and downhole fluids.

SUBTASK 5.C; Analysis of O-18 and deuterium in water and C-13, O-18 and S-34 in dissolved CO_2, H_2S, and SO_4, and tritium and C-14 in water. Active rare gases will be chemically analyzed and certain gas components (H_2, CH_4, CO_2, H_2O) will be analyzed isotopically for deuterium, C-13 and C-14.

SUBTASK 5.D; These analyses will be interpreted to help define the recharge areas of the water, the depth and direction of circulation, the residence time of the water in the aquifer, the temperatures in the producing zones and deeper zones below the levels of drilling, and the origin of the water, gases and dissolved constituents.

1978. Continue sampling and isotopic analysis program in conjunction with the CFE standard geochemical analyses.

1979. Complete analysis studies and evaluate the fluid system of the resource.

3. Responsibilities.

A. ERDA

(1) With assistance from CFE, ERDA will design a program of isotope studies and the collection of fluid samples set forth in the Subtasks.

(2) ERDA will assume lead responsibility for the analysis and the interpretation of such analysis of fluid samples set forth in the Subtasks.

B. CFE

(1) CFE will participate with ERDA in the planning of the isotope studies and water samples set forth in the Subtasks and in Paragraph A(1) above.

(2) CFE will ensure ERDA access to the wells and springs for sampling purposes.

(3) CFE will participate in the interpretation of isotope analytical data.

TASK 6: SUBSIDENCE

1. Objectives. The objectives of this task are to establish and maintain a joint crustal-strain monitoring program in the Mexicali Valley. Regional and local measurements of vertical and horizontal movement will provide base level information regarding changes related to regional tectonic strain and to local subsidence from geothermal fluid withdrawal.

2. Research and Time Schedule.

1977-1978. Three types of surveys suited to detecting ground deformation will be performed.

SUBTASK 6.A; FIRST ORDER LEVELING: A network of first-order leveling will be established extending from a National Geodetic Survey benchmark at the international boundary southward through the Cerro Prieto geothermal area and back to another National Geodetic Survey benchmark on the border via a different route, to identify and monitor vertical crustal movement. This first-order control would tie to a local network of benchmarks that extends throughout the Cerro Prieto production area. The network is periodically surveyed to second-order accuracy by CFE. An estimated 160 Km. of leveling would complete this first-order loop.

SUBTASK 6.B; REGIONAL TRILATERATION NET: Establish and survey a regional geodolite network of trilateration, southward from the international boundary to beyond Cerro Prieto to monitor crustal strain. This effort will require repeated flights along the line of survey while long-distance laser measurements are being made. The plane making these measurements will not be required to land in Mexico. A helicopter will be utilized to transport survey crews to inaccessible locations. The helicopter will be based in the United States but will land to discharge and pick up personnel and to refuel.

SUBTASK 6.C; LOCAL HORIZONTAL NET: Establish and survey a local network of horizontal electronic distance measurements, tied to the regional network, to monitor strain in the Cerro Prieto geothermal area.

1979. The three networks will be selectively resurveyed and expanded.

1980. The three networks will be completely resurveyed. All data will be adjusted and interpreted. An interpretive report will be issued.

3. Responsibilities.

A. ERDA

ERDA will assume responsibility for the execution of Subtasks 6B and 6C.

B. CFE

(1) CFE will assume responsibility for Subtask 6A.

(2) CFE will provide at least one person per crew or vehicle involved in the survey undertaken by ERDA pursuant to Paragraph A above.

(3) CFE will participate in the interpretation of collected data.

TASK 7: CERRO PRIETO CONFERENCES

1978 and 1979. Conferences will be held alternately in Baja California and California to insure accurate interpretation of Cerro Prieto research information, and to encourage its application at other geothermal development sites. The conferences will employ seminars and workshops,as applicable, to transfer the knowledge gained at Cerro Prieto to parties involved in geothermal activities at other hydrothermal areas in the United States and Mexico. Attendees will include geothermal developers, landowners, engineering firms, utilities, industrial groups, government representatives, research scientists and the interested public from both countries.

Responsibilities.

A. ERDA

With the assistance of CFE, ERDA shall be responsible for the organization of the conference(s) to be held in California.

B. CFE

With the assistance of ERDA, CFE shall be responsible for the organization of the conference(s) to be held in Baja California.