GL01494

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-524-3422

May 25, 1994

ING. SAUL VENEGAS SALGADO
Jefe del Departamento de Exploracion
GERENCIA DE PROYECTOS GEOTERMOELECTRICOS
COMISION FEDERAL DE ELECTRICIDAD
Morelia Michoacan
Mexico

Dear Sr. Venegas:

Thank you for your FAX of 20 May 1994 informing me of the transmittal of the Ceboruco Geothermal Reconnaissance Area geoscience data. We received the data package in good condition from United Parcel Service (via AEROFLASH). The reports and data seem to be well organized. I intend to begin a review of these data and reports in June.

Dr. Wannamaker will be in the field through early July but should be able to begin a review of the magnetotelluric data after his return to Salt Lake City. Please inform Ing. José Francisco Arellano Guadarrama of this schedule. We will contact you for additional information when questions arise.

Sincerely,

Howard P. Ross

Howard P. Ross
Section Head/Applied Geophysica

cc: P.M. Wright
P.E. Wannamaker

COMISION FEDERAL DE ELECTRICIDAD
GERENCIA DE PROYECTOS GEOTERMOELECTRICOS

FAX

ENTREGUESE A:

NOMBRE: HOWARD P. ROSS
CIA. O DEPTO.: SECTION HEAD/APPLIED GEOPHYSICS-UNIVERSITY OF UTAH SEARCH INSTITUTE
CIUDAD: SALT LAKE CITY, UTAH, U.S.A.
FAX No.: (801) 584-4453

DE PARTE DE:

NOMBRE: ING. GERMAN R. RAMIREZ SILVA
DEPARTAMENTO: DE EXPLORACION OFNA. DE GEOLOGIA

FECHA: 11 MAYO 1994

MENSAJE ADICIONAL:

FAX: 91-43-14-47-35

EL ENVIO CONTIENE 2 PAGINAS INCLUYENDO ESTA PORTADA. SI TIENE PROBLEMAS EN LA RECEPCION, COMUNIQUESE AL TEL.: 91-43- 14-49-40 MORELIA MICHOACAN

COMISION FEDERAL DE ELECTRICIDAD
GERENCIA DE PROYECTOS GEOTERMOELECTRICOS

Ofic. No. J3111/GRRS/003/94.

Morelia, Mich., may 10th, 1994.

HOWARD P. ROSS
SECTION HEAD/APPLIED GEOPHYSICS
UNIVERSITY OF UTAH RESEARCH INSTITUTE
SALT LAKE CITY, UTAH
U.S.A.

Dear Howard:

We really appreciate your interest in evaluating remote sensing data from an specific area, into the Mexican Geothermal Exploration Program.

The Ceboruco geothermal zone is the chosen area, at the Mexico western part, which is delineated by next coordinates:

Latitude:	20°50'	-	21°30'
Longitude:	104°30'	-	105°00'

Please, let us know the data cost, that will allow us to review our options and define the project starting.

Sincerely yours,

United States Government **Department of Energy**

memorandum

DATE: March 1, 1995

REPLY TO ATTN OF: EE-122 (Allan J. Jelacic, 6-6054)

SUBJECT: DOE - CFE Technical Meeting

TO: Distribution List

The final technical meeting of the current 5-year DOE-CFE Geothermal Agreement is confirmed for April 25-26, 1995, in Mexicali, BCN.

U.S. co-principal investigators are reminded that camera-ready final reports are due at the meeting for inclusion in the Proceedings of the final technical meeting. Further information about the meeting site, agenda, and accommodations will be distributed as soon as possible.

Allan J. Jelacic, Acting Director
Geothermal Division
Energy Efficiency and Renewable Energy

OPTIONAL FORM 99 (7-90)

FAX TRANSMITTAL # of pages ► 1

To H.B. Ross	From R. Fortuna
Dept./Agency —	Phone # (202)586-1711
Fax # (801)584-4453	Fax # (202)586-8185

NSN 7540-01-317-7368 5099-101 GENERAL SERVICES ADMINISTRATION

DISTRIBUTION LIST

Name	Organization	Telephone	Fax	
U.S. Co-Principal Investigators:				
1. Marcello Lippmann	LBL	(510) 486-5035	486-5686	✓
Alfred Truesdell	Cons.	(415) 322-6135	324-4009	✓
2. Paul Kruger	SGP	(415) 725-2382	725-8662	✓
3. John W. Lund	OIT	(503) 885-1516	885-1854	✓
4. Joseph N. Moore	UURI	(801) 584-4428	584-4453	✓
5. P.E. Wanamaker	UURI	(801) 584-4422	584-4453	✓
H.P. Ross	UURI	(801) 584-4444	584-4453	✓
6. Marc Fioravanti	SGP	(415) 725-2580	725-8662	✓
~~Paul Kruger~~	~~SGP~~	~~(415) 725-2382~~	~~725-8662~~	
7. G.D. Nash	UURI	(801) 584-4444	584-4453	✓
8. Gary Sharp	Cons.	(510) 838-5623	838-3121	✓
Glenn Horton	Unocal	(707) 545-7600	545-8746	✓
9. Lance Hayes	Biphase	(714) 524-3338	524-3341	✓
10. Mike Shook	EG&G	(208) 526-9824	526-9822	✓
Agreement Coordinators				
Allan J. Jelacic	DOE	(202) 586-6054	586-2235	
Gladys Hooper	DOE	(202) 586-1146	586-2235	
Ray Fortuna	DOE	(202) 586-1711	586-2235	
Gerardo Hiriart	CFE	(011-52) 431-43970	431-44735	
Luis Quijano	CFE	(011-52) 431-43970	431-44735	
Hector Gutierrez	CP	(011-52) 65-536870	65-536269	
Participants				
Dick Benoit	Oxbow	(702) 825-4345	825-2838	✓
Tom Box	Calpine	(707) 527-6700	544-2422	✓
Sabodg Garg	S-Cubed	(619) 587-8438	755-0474	✓
Mohinder Gulati	Unocal	(213) 977-7496	977-6333	✓
Jim Lovekin	Cal Energy	(619) 499-2322	499-2308	✓
Tony Menzies	GeothermEx	(510) 527-9876	527-8164	✓
Jose Perez	Magma	(619) 348-4023	348-4021	✓
Joel Renner	INEL	(208) 526-9824	526-0969	✓

[redacted]

DOE-CFE Geothermal Agreement
Memorandum
27 February 1995

To: Distribution; U.S. Participants
From: A.J. Jelacic, EE-122
Subject: Final Technical Meeting

The Final Technical Meeting of the current 5-year DOE-CFE Geothermal Agreement has been confirmed for 25-26 April in Mexicali, BCN.

U.S. Co-Principal Investigators are reminded that camera-ready Final Reports are due at the meeting for inclusion in the Proceedings of the Final Technical Meeting.

Further information about the meeting site, Agenda, and accomodations will be distributed as soon as possible.

Meeting Cancelled

COMISION FEDERAL DE ELECTRICIDAD
GERENCIA DE PROYECTOS GEOTERMOELECTRICOS

FAX

ENTREGUESE A:

NOMBRE: HOWARD P. ROSS
CIA. O DEPTO.: SECTION AHEAD/APPLIED GEOPHYSICS (UURI)
CIUDAD: SALT LAKE CITY, UTAH-USA
FAX No.: (801) 584-4453.

DE PARTE DE:

NOMBRE: ING. SAUL VENEGAS SALGADO
DEPARTAMENTO: DE EXPLORACION

FECHA: 20 MAYO 1994

MENSAJE ADICIONAL:

011-524-314-4735

Successful FAX NO. → 011-524-43-14-47-35

FAX: 91-43-14-47-35

EL ENVIO CONTIENE 2 PAGINAS INCLUYENDO ESTA PORTADA. SI TIENE PROBLEMAS EN LA RECEPCION, COMUNIQUESE AL TEL.: 91-43-14-49-40 MORELIA MICHOACAN

COMISION FEDERAL DE ELECTRICIDAD
GERENCIA DE PROYECTOS GEOTERMOELECTRICOS

Ofic. No. J3110/SVS/047/94.

Morelia, Mich., may 20th, 1994.

JOSEPH N. MOORE
SECTION HEAD/APPLIED GEOPHYSICS
UNIVERSITY OF UTAH RESEARCH INSTITUTE
SALT LAKE CITY, UTAH
U.S.A.

Dear Joseph:

I'm sending to you rock samples from 10-1200 m depth, from LV-3 well, of Tres Vírgenes Geothermal project.

I think with this information, you are able to start the joint - study on petrographic and fluid inclusion analysis, to allow us to develope a better understanding of altered rocks and their significance, permeability structure of the reservoir and characteristics of thermal system.

Sincerely yours,

ING. SAUL VENEGAS SALGADO
JEFE DEL DEPTO. DE EXPLORACION

C.c.p. Archivo.
Minutario.

SVS/GRS/rdlb.

COMISION FEDERAL DE ELECTRICIDAD
GERENCIA DE PROYECTOS GEOTERMOELECTRICOS

FAX

ENTREGUESE A: HOWARD P. ROSS.-SECTION HEAD/APPLIED GEOPHYSICS
NOMBRE:
CIA. O DEPTO.: UURI
CIUDAD: SALK LAKE CITY
FAX No.: (801) 584-4453

DE PARTE DE:
NOMBRE: ING. SAUL VENEGAS SALGADO
DEPARTAMENTO: JEFE DEL DEPARTAMENTO DE EXPLORACION.

FECHA: MAYO 20 DE 1994.

MENSAJE ADICIONAL:

011 524·43·14·47·35

FAX: ~~91~~-43-14-47-35

EL ENVIO CONTIENE 4 PAGINAS INCLUYENDO ESTA PORTADA. SI TIENE PROBLEMAS EN LA RECEPCION, COMUNIQUESE AL TEL.: 14 49 40 EN MORELIA MICHOACAN

GERENCIA DE PROYECTOS GEOTERMOELECTRICOS

SUBGERENCIA DE ESTUDIOS
DEPARTAMENTO DE EXPLORACION
OFICINA DE GEOFISICA

HOWARD P. ROSS
SECTION HEAD/APPLIED GEOPHYSICS

UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, STE C
SALK LAKE CITY
UT 84109-1295
PHONE: (801) 584-4422
FAX: (801) 584-4453

In connection with the geophysical studies at the Ceboruco Geothermal Reconnaissance Area, we inform you, that we prepared the information listed in the attached relation.

This information was sent to you by express service. **AEROFLASH**, date May, 19 and parcel number 1009499.

The information is according with your plan to begin a review analisis in orden to define the especific future actions with Wannamaker, when you define the best date.

If you have any question about that don't hesitate to contact us.

Sicerely

ING. SAUL VENEGAS SALGADO
Jefe del Departamento de Exploración

Ccp. **Fís. José Luis Quijano León.**
Subgerente de Estudios.
Ccp. **Ing. José Francisco Arellano Guadarrama.**
jefe de la Oficina de Geofísica.

RELACION DE INFORMACION PARA EL PROYECTO CFE-DOE

EL CEBORUCO, NAY.

✓- PLANO DE ANOMALIA DE BOUGUER.

✓- CARACTERISTICAS GENERALES DEL LEVANTAMIENTO GRAVIMETRICO.

✓- CINTA MAGNETICA CON LA BASE DE DATOS MAGNETOTELURICOS, UTILIZANDO SOFTWARE GEOTOOLS, EN HARWARE SUN SPARC.

✓- COLUMNA LITOLOGICA (POZO CB-1).

✓- REGISTROS DE TEMPERATURA (POZO CB-1).

✓- GEOLOGIA REGIONAL DEL GRABEN TEPIC-IXTLAN, NAY. (INFORME 04/91).

✓- "PROYECTO GEOTERMICO EL CEBORUCO, NAY." -ESTADO ACTUAL DE LA EXPLORACION. (INFORME DEX/CEB/002/92.).

✓- INTEGRACION DE LOS ESTUDIOS GEOELECTRICOS DE RESISTIVIDAD EN "EL CEBORUCO, NAY.". (INFORME No. 02/92).

✓- INTERPRETACION CUALITATIVA DEL ESTUDIO MAGNETOTELURICO, REALIZADO EN EL -- CEBORUCO, NAY. (INFORME 04/93).

✓- ESTUDIO AEROMAGNETICO REGIONAL DEL SE DE NAYARIT. (EL CEBORUCO-SAN PEDRO-- TEPETILTIC). PROCESAMIENTO DIGITAL Y DESCRIPCION CUALITATIVA. (INFORME 15/91).

✓- ESTUDIO MAGNETOTELURICO DE LA REGION DEL CEBORUCO DOMO SAN PEDRO DEL ESTADO DE NAYARIT. INFORME FINAL (NOVIEMBRE - 1992).

EXPERTOS EN MENSAJERIA

AEROFLASH

SU ENVIO, SEGURO VA QUE VUELA

UN PRODUCTO MAS DE SERPAPROSA

CONTRATO:

FOLIO: 1009499

CIUDAD DE DESTINO: SALT LAKE CITY, UT U.S.A.

FACTURAR EN:

REMITENTE

ING. SAUL VENEGAS SALGADO

RAZON SOCIAL: GCIA. DE PROY. GEOTERMOELECTRICOS

NOMBRE/DEPARTAMENTO: EXPLORACION

DIRECCION: ALEJANDRO VOLTA No.655, COL.ELECTRICISTAS

CIUDAD: MORELIA ESTADO: MICH. PAIS: MEXICO

CODIGO POSTAL: 58290 TELEFONO: 14 49 40

NOMBRE: ARACELI FIRMA:

FECHA: 19 DE MAYO DE 1994

CONSIGNATARIO

HOWARD P. ROSS

RAZON SOCIAL: EARTH SCIENCE LABORATORY APPLIED GEOPHYSICS

NOMBRE/DEPARTAMENTO:

DIRECCION: 391 CHIPETA WAY, STE C

CIUDAD: SALT LAKE ESTADO: UT PAIS: U.S.A.

CODIGO POSTAL: 84109-1295 TELEFONO: (801)584 44 22

NOMBRE: FIRMA:

FECHA: HORA:

☐ INTER-OFICINAS ☐ CARGAFLASH ☐ AEROFLASH ☐ CHEQUEFLASH ☒ INTERNACIONAL ☒ ENTREGA DOM.

CARACTERISTICAS DE ENVIO: PAQUETE (DOCUMENTOS)

AEROFLASH

NUM.:

FECHA: 19-05-94

HORA: 18:15

0020074 C

☐ VALIJAS
☐ ENVASES
☒ PAQUETES
☐ SOBRES

CANTIDAD: UNO

CLIENTE

PESO:

VOLUMEN: ____X ____X ____

COMISION FEDERAL DE ELECTRICIDAD
GERENCIA DE PROYECTOS GEOTERMOELECTRICOS

Ofic. No. J3111/GRRS/003/94.

Morelia, Mich., may 10th, 1994.

HOWARD P. ROSS
SECTION HEAD/APPLIED GEOPHYSICS
UNIVERSITY OF UTAH RESEARCH INSTITUTE
SALT LAKE CITY, UTAH
U.S.A.

Dear Howard:

We really appreciate your interest in evaluating remote sensing data from an specific area, into the Mexican Geothermal Exploration Program.

The Ceboruco geothermal zone is the chosen area, at the Mexico western part, which is delineated by next coordinates:

Latitude:	20°50'	-	21°30'
Longitude:	104°30'	-	105°00'

Please, let us know the data cost, that will allow us to review our options and define the project starting.

Sincerely yours,

ING. GERMAN R. RAMIREZ SILVA
JEFE DE LA OFNA. DE GEOLOGIA

C.c.p. Archivo.
Minutario.

GRRS/rdlb.

cfe.sow

COOPERATIVE GEOTHERMAL STUDIES - 1994
U.S. DEPARTMENT OF ENERGY and COMISION FEDERAL DE ELECTRICIDAD

INTRODUCTION

Under the current DOE-GD and CFE Cooperative Agreement, the University of Utah Research Institute (UURI) will complete studies on three tasks described below, in cooperation with CFE colleagues and discuss the results in joint reports.

SCHEDULE

The tasks described in the Statement of Work will be completed in the period June 1 to December 31, 1994.

STATEMENT OF WORK

Task 1. Ceboruco Geothermal Reconnaissance

UURI will review existing geologic, geophysical, and drilling data and interpretations for the Ceboruco Reconnaissance area, and critique this work and the overall exploration strategy. UURI will review the magnetotelluric (MT) survey data and interpretations, and will work with CFE geophysicists to complete numerical interpretations of selected MT data.

UURI studies will be conducted by Drs. P.E. Wannamaker and H.P. Ross.

Task 2. Ceboruco Geothermal Area - Remote Sensing Study

UURI will evaluate existing Landsat 5, Thematic Mapper, or other appropriate spectral data available for the Ceboruco area and recommend its purchase to CFE. CFE will send a scientist to UURI to become familiar with UURI remote sensing interpretation procedures and to assist in the interpretation of the Ceboruco data. The interpretation will consist of: 1) Data downloading from 9-track tape; 2) Preprocessing (atmospheric correction and rectification; 3) Hydrothermal alteration mapping; 4) Lineament mapping; and 5) Data input and characterization in a GIS environment.

UURI studies will be conducted by Greory D. Nash.

Task 3. Geochemical Studies of the Tres Virgenes Geothermal Field

UURI will collaborate with CFE geologists on geologic and geochemical studies of the Tres Virgenes field by completing petrographic and fluid-inclusion analyses in support of CFE studies.

UURI studies will be conducted by Dr. J. N. Moore

STATEMENT OF WORK - REMOTE SENSING

The following work will be performed using Landsat 5, Thematic Mapper data, or other appropriate spectral data for the Ceboruco, Mexico geothermal area.

1. Data downloading from 9-track tape.
2. Preprocessing (atmospheric correction and rectification).
3. Hydrothermal alteration mapping.
4. Lineament mapping.
5. Data input and characterization in a GIS environment.

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-524-3422

May 25, 1994

ING. SAUL VENEGAS SALGADO
Jefe del Departamento de Exploracion
GERENCIA DE PROYECTOS GEOTERMOELECTRICOS
COMISION FEDERAL DE ELECTRICIDAD
Morelia Michoacan
Mexico

Dear Sr. Venegas:

Thank you for your FAX of 20 May 1994 informing me of the transmittal of the Ceboruco Geothermal Reconnaissance Area geoscience data. We received the data package in good condition from United Parcel Service (via AEROFLASH). The reports and data seem to be well organized. I intend to begin a review of these data and reports in June.

Dr. Wannamaker will be in the field through early July but should be able to begin a review of the magnetotelluric data after his return to Salt Lake City. Please inform Ing. José Francisco Arellano Guadarrama of this schedule. We will contact you for additional information when questions arise.

Sincerely,

Howard P. Ross

Howard P. Ross
Section Head/Applied Geophysica

cc: P.M. Wright
    P.E. Wannamaker

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-584-4422

March 10, 1994

Ing. José Francisco Arellano Guadarrama
Jefe de la Oficina de Geofísica
Comisión Federal de Electricidad
Morelia, Michoacan
Mexico

Dear Francisco:

Thank you for your FAX of March 3rd. Enclosed is a copy of our Project Plan for the joint DOE-CFE study of the Ceboruco data (mainly MT). Dr. Philip Wannamaker is beginning a substantial MT survey effort in the southeastern United States this month and will be away much of the time until June. He will be able to review the CFE MT data in late June and July. I propose that you send the available gravity, aeromagnetic, geology, MT, and drilling data with reports to me, so that I can begin my review as time permits. I will then be able to help Dr. Wannamaker focus his efforts for the detailed MT review.

Dr. Mike Wright agrees this is the best way to proceed in view of everyone's other commitments.

Sincerely,

Howard

Howard P. Ross
Section Head/Applied Geophysics

HPR/je

Enclosure

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
15 FEBRUARY 1994

GEOPHYSICAL STUDIES
CEBORUCO GEOTHERMAL RECONNAISSANCE AREA

Phillip E. Wanamaker	Jose Francisco Arellano Guadarrama
Howard P. Ross	Senior Geophysicist
UURI	Gerencia
DOE	CFE

Background:

UURI and CFE completed cooperative geophysical studies of the Los Azufres geothermal area in an earlier DOE-CFE Cooperative Agreement, and these were reported in the 1989 DOE-CFE Research Proceedings. The Ceboruco area, within the western Neovolcanic Belt, was identified as a promising geothermal area for additional geophysical studies during the 1989-1994 agreement. CFE completed extensive gravity, aeromagnetic, and magnetotelluric (MT) studies in the greater Ceboruco area (30-40 km N-S by 40-50 km E-W) but UURI was unable to participate due to lack of project funding. Initial drilling results, including a test hole 1800 m deep sited on MT results, have been disappointing and CFE geophysicists have requested a review of contractor geophysical data, interpretations, and exploration strategy.

Objective:

This joint study will review the exploration strategy in general, and the MT data and interpretation in particular in the Ceboruco area of the prospective western Neovolcanic Belt. The identification of any problem areas will improve exploration results within this province, and perhaps the Cascades in the western United States.

Program for 1994:

To proceed in this research with the most efficiency, CFE will first submit gravity, aeromagnetic, geologic, MT, TDEM and other data in hardcopy for UURI review and study. UURI will complete a preliminary data review and identify specific MT data for reinterpretation. CFE will select key digital data and supporting information and bring these to UURI. A CFE geophysicist will spend one to two weeks at UURI reviewing MT data with Phil Wannamaker and completing new 1-D (and 2-D, if practical) interpretations. CFE and UURI geophysicists will complete a report describing new results and recommendations for future studies and improved exploration efforts.

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
15 FEBRUARY 1994

THE JOINT TESTING OF REMOTE SENSING TECHNIQUES AND EQUIPMENT FOR USE IN GEOTHERMAL EXPLORATION

Gregory D. Nash
UURI
DOE

Jose Francisco Arellano Guadarrama
Senior Geophysicist
Gerencia
CFE

Background:

UURI and CFE conducted a joint remote sensing study for the Los Azufres Geothermal Field in an earlier DOE-CFE Cooperative Agreement with the findings being reported in the 1989 DOE-CFE Research Proceedings. This study led to the conclusion that remote sensing techniques can be useful in geothermal exploration. It was shown that remote sensing can be effective in the early phases of exploration, particularly in determining hydrothermally altered zones and geologic structures conducive to hydrothermal fluid circulation. It was also stated that remote sensing data can be an important addition to a total exploration program when added as a correlative component to other geologic and geophysical data.

Objective:

This study will evaluate remote sensing data for an area chosen by CFE. The area will be delineated by the CFE with a universal coordinate system such as latitude and longitude or UTM. UURI personnel will then determine the availability, quality and cost of the data. This will allow CFE to review their options and request the data of their choice. One or more representatives of CFE will then travel to UURI for interactive work with UURI personnel in processing and interpreting the data. This will also allow the CFE personnel to evaluate various remote sensing and GIS hardware and software platforms for potential integration into the CFE system in the future.

Program for 1994:

The data for the chosen location(s)will be interactively processed by both UURI and CFE personnel to determine geomorphic indications of subsurface structure and to map hydrothermally altered areas. The processed data will then be added to a GIS database to allow the easy integration of other geologic and geophysical data for correlation purposes. In addition, the CFE personnel will be given an introduction to the use of hyperspectral (high spectral resolution) data in exploration. A report will then be written jointly by participating UURI and CFE investigators describing the results of the study and recommendations for future studies.

Geochemical Studies
Tres Virgenes Geothermal Field

Joseph N. Moore — UURI — DOE

Saul Venegas Salgado — Gerencia — CFE

Background:

Tres Virgenes is one of several potential high temperature geothermal resources that is currently being explored by CFE. This geothermal system, which is associated with young volcanic activity, is developed within the granitic basement rocks. One deep exploratory well has been drilled but the well was not productive. A second well is currently being drilled.

Objectives:

Granitic host rocks throughout the world have proven to be difficult to explore and develop because of their inherently low permeabilities. Exploration of these reservoirs is further hindered by the common presence of multiple hydrothermal events that make the normally utilized mineralogic indicators of permeability difficult to interpret. Despite these difficulties, granitic reservoirs have proven to be attractive targets in the Unites States (e.g. Coso, Steamboat Hot Springs, Roosevelt Hot Springs, The Geysers) and Guatemala.

The joint study we propose has two major objectives. First, it will directly assist CFE in their exploration program of Tres Virgenes. Secondly, it will provide DOE and the U. S. industry with important new data on the physical and chemical characteristics of granitic reservoirs. These data will assist in both the development of our existing fields and in the exploration of new systems where U. S. interests are involved (e.g. Meager Creek, British Columbia).

Program for 1994:

We propose to jointly collaborate on geologic and geochemical studies of Tres Virgenes. UURI will work with CFE geologists to determine the mineralogies of the altered rocks and their significance, develop a better understanding of the permeability structure of the reservoir, and characterize the chemical evolution and characteristics of the thermal system. CFE will provide samples of the rocks and fluids to UURI. We will conduct petrographic (thin section, X-ray diffraction, and SEM) and fluid inclusion analyses in support of the work being conducted by CFE. CFE and UURI will jointly prepare a report on the results of this work upon completion of the studies.

COMISION FEDERAL DE ELECTRICIDAD
GERENCIA DE PROYECTOS GEOTERMOELECTRICOS

Morelia, Mich., March 3 th, 1994.

UNIVERSITY OF UTAH RESEARCH INSTITUTE
FAX (801) 584-4453.
SALT LAKE CITY, UTAH, USA.

Dear Ross:

Recent results provided by the CB-1 borehole at El Ceboruco geothermal field, make necessary a reinterpretation of geophsical data, particularly MT. Do you know if Wannamaker will be available to cooperate with us in this task?.

As we talked in Mexicali this could be part of a new DOE -CFE agreement, but we can look for an alternative way.

If Wannamaker is available what should be the next step to follow?.

Best regards for Mike Wirght and Joseph Moore.

Sincerely

ING. JOSE FRANCISCO ARELLANO GUADARRAMA
JEFE DE LA OFICINA DE GEOFISICA

C.C.P.: ING. SAUL VENEGAS SALGADO.-JEFE DEPTO. DE EXPLORCION.
ARCHIVO.
MINUTARIO.

JFAG/mfd*

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
15 FEBRUARY 1994

GEOPHYSICAL STUDIES
CEBORUCO GEOTHERMAL RECONNAISSANCE AREA

Phillip E. Wanamaker	Jose Francisco Arellano Guadarrama
Howard P. Ross	Senior Geophysicist
UURI	Gerencia
DOE	CFE

Background:

UURI and CFE completed cooperative geophysical studies of the Los Azufres geothermal area in an earlier DOE-CFE Cooperative Agreement, and these were reported in the 1989 DOE-CFE Research Proceedings. The Ceboruco area, within the western Neovolcanic Belt, was identified as a promising geothermal area for additional geophysical studies during the 1989-1994 agreement. CFE completed extensive gravity, aeromagnetic, and magnetotelluric (MT) studies in the greater Ceboruco area (30-40 km N-S by 40-50 km E-W) but UURI was unable to participate due to lack of project funding. Initial drilling results, including a test hole 1800 m deep sited on MT results, have been disappointing and CFE geophysicists have requested a review of contractor geophysical data, interpretations, and exploration strategy.

Objective:

This joint study will review the exploration strategy in general, and the MT data and interpretation in particular in the Ceboruco area of the prospective western Neovolcanic Belt. The identification of any problem areas will improve exploration results within this province, and perhaps the Cascades in the western United States.

Program for 1994:

To proceed in this research with the most efficiency, CFE will first submit gravity, aeromagnetic, geologic, MT, TDEM and other data in hardcopy for UURI review and study. UURI will complete a preliminary data review and identify specific MT data for reinterpretation. CFE will select key digital data and supporting information and bring these to UURI. A CFE geophysicist will spend one to two weeks at UURI reviewing MT data with Phil Wannamaker and completing new 1-D (and 2-D, if practical) interpretations. CFE and UURI geophysicists will complete a report describing new results and recommendations for future studies and improved exploration efforts.

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
15 FEBRUARY 1994

THE JOINT TESTING OF REMOTE SENSING TECHNIQUES AND EQUIPMENT FOR USE IN GEOTHERMAL EXPLORATION

Gregory D. Nash
UURI
DOE

Jose Francisco Arellano Guadarrama
Senior Geophysicist
Gerencia
CFE

Background:

UURI and CFE conducted a joint remote sensing study for the Los Azufres Geothermal Field in an earlier DOE-CFE Cooperative Agreement with the findings being reported in the 1989 DOE-CFE Research Proceedings. This study led to the conclusion that remote sensing techniques can be useful in geothermal exploration. It was shown that remote sensing can be effective in the early phases of exploration, particularly in determining hydrothermally altered zones and geologic structures conducive to hydrothermal fluid circulation. It was also stated that remote sensing data can be an important addition to a total exploration program when added as a correlative component to other geologic and geophysical data.

Objective:

This study will evaluate remote sensing data for an area chosen by CFE. The area will be delineated by the CFE with a universal coordinate system such as latitude and longitude or UTM. UURI personnel will then determine the availability, quality and cost of the data. This will allow CFE to review their options and request the data of their choice. One or more representatives of CFE will then travel to UURI for interactive work with UURI personnel in processing and interpreting the data. This will also allow the CFE personnel to evaluate various remote sensing and GIS hardware and software platforms for potential integration into the CFE system in the future.

Program for 1994:

The data for the chosen location(s) will be interactively processed by both UURI and CFE personnel to determine geomorphic indications of subsurface structure and to map hydrothermally altered areas. The processed data will then be added to a GIS database to allow the easy integration of other geologic and geophysical data for correlation purposes. In addition, the CFE personnel will be given an introduction to the use of hyperspectral (high spectral resolution) data in exploration. A report will then be written jointly by participating UURI and CFE investigators describing the results of the study and recommendations for future studies.

Geochemical Studies
Tres Virgenes Geothermal Field

Joseph N. Moore
UURI
DOE

Saul Venegas Salgado
Gerencia
CFE

Background:

Tres Virgenes is one of several potential high temperature geothermal resources that is currently being explored by CFE. This geothermal system, which is associated with young volcanic activity, is developed within the granitic basement rocks. One deep exploratory well has been drilled but the well was not productive. A second well is currently being drilled.

Objectives:

Granitic host rocks throughout the world have proven to be difficult to explore and develop because of their inherently low permeabilities. Exploration of these reservoirs is further hindered by the common presence of multiple hydrothermal events that make the normally utilized mineralogic indicators of permeability difficult to interpret. Despite these difficulties, granitic reservoirs have proven to be attractive targets in the Unites States (e.g. Coso, Steamboat Hot Springs, Roosevelt Hot Springs, The Geysers) and Guatemala.

The joint study we propose has two major objectives. First, it will directly assist CFE in their exploration program of Tres Virgenes. Secondly, it will provide DOE and the U. S. industry with important new data on the physical and chemical characteristics of granitic reservoirs. These data will assist in both the development of our existing fields and in the exploration of new systems where U. S. interests are involved (e.g. Meager Creek, British Columbia).

Program for 1994:

We propose to jointly collaborate on geologic and geochemical studies of Tres Virgenes. UURI will work with CFE geologists to determine the mineralogies of the altered rocks and their significance, develop a better understanding of the permeability structure of the reservoir, and characterize the chemical evolution and characteristics of the thermal system. CFE will provide samples of the rocks and fluids to UURI. We will conduct petrographic (thin section, X-ray diffraction, and SEM) and fluid inclusion analyses in support of the work being conducted by CFE. CFE and UURI will jointly prepare a report on the results of this work upon completion of the studies.

United States Government **Department of Energy**

memorandum

DATE: February 14, 1994

REPLY TO ATTN OF: EE-122 (John E. Mock, 6-5340)

SUBJECT: Summary of Proposed DOE/CFE Project Due February 28, 1994

TO: Distribution

I appreciated your participation in the recent joint DOE/CFE meeting in Mexicali, Mexico. The meeting was an excellent example of cooperation among our two countries, an achievement that will set the stage for similar future success.

It was agreed at the meeting that by the end of February, you would provide a summary of a proposed project for our proceedings. An example project summary is enclosed to help in the preparation of your submission.

To ensure timely progress of our efforts, please provide me with your summary by February 28, 1994.

Once again, thank you for your participation and ongoing efforts.

Jod

John E. Mock, Director
Geothermal Division
Office of Renewable Energy Conversion
Energy Efficiency and Renewable Energy

DISTRIBUTION: (FAX)

J. Dunn (SNL)	(505) 844-3952
M. Fioravanti (SGP)	(415) 725-8662
M. Gulati (Unocal)	(213) 977-6333
P. Kruger (SGP)	(415) 725-8662
J. Lovekin (CECI)	(619) 499-2308
J. Lund (OIT)	(503) 885-1754
J. Moore (UURI)	(801) 584-4453
G. Nash (UURI)	(801) 584-4453
H. Ross (UURI)	(801) 584-4453
B. Robinson (LANL)	(505) 667-8487
M. Wright (UURI)	(801) 584-4453

CC:

E. Hughes (EPRI)	(415) 855-2954
M. Lippman (LBL)	(510) 486-5856
A. Truesdell (LBL)	(510) 486-5856
J. Renner (INEL)	(208) 526-0969
M. Shook (INEL)	(208) 526-0969

2/208

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
25 January 1994

CHEMICAL RESERVOIR ENGINEERING AT SELECTED LOS AZUFRES PRODUCTION WELLS

Paul Kruger
SGP
DOE

Hector Gutierrez
Gerencia
CFE

Background:

The joint study has been underway since the 1982 startup of the initial 5-MWe Units at Los Azufres to examine thermal drawdown in the production zones based on combined analyses of the thermodynamic and chemical behavior during production. Analyses were prepared for several wells after 2.5, 4, and 5 years of production. Analysis of these wells were continued with data through 1992. New data on sustained production at several wells prior to generator startup have been acquired. The re-evaluation of the results for the additional data should be of value in comparing the effects of the early drawdown.

Objective:

The joint study evaluates the extent of the changes observed around five production wells in three structural zones where 5-MWe Units are in service in the potentially large Los Azufres geothermal field. The evaluation provides information concerning the extent of thermal decline in production fluid and hydraulic drawdown in the reservoir.

Program for 1994:

The study consists of each-sample and semester-averaged analysis of fluid production with respect to temperature, enthalpy, and thermal extraction rate, chemical characteristics with respect to near-well and far-field geochemical temperatures, and drawdown evaluation based on saturation temperatures and total production volume. For the study, evaluation will be completed for wells Az-5 and Az-13 in the Maritaro zone, well Az-9 in the El Chino zone, and wells Az-16AD and Az-22 in the Tejamaniles zone at Los Azufres.

3/308

DOE-CFE GEOTHERMAL AGREEMENT

Second Technical Meeting
25-26 January 1994
Mexicali, B.C.

Draft Agenda
(draft pk+hgp:21Jan94)

I. Review of Prior Joint Studies

	Principal Investigators	
	DOE	CFE
1. Los Azufres: Tracers	B. Robinson (LANL)	H. Gutierrez
2. Los Azufres: ChemResEngr	P. Kruger (SGP)	H. Gutierrez
3. Tres Virgenes: Exploration	J. Moore (UURI)	S. Venegas
4. Ceboruco: Exploration	M. Wright (UURI)	F. Arrellano
5 Direct Uses	J. Lund (OIT)	M. Rangel
6. Geothermal Hydrogen	M. Fioravanti (SGP)	M. Rangel
7. Cerro Prieto: Injection	M. Lippmann (LBL)	H. Gutierrez M. Ribo
8. Cerro Prieto: ß-Reservoir	A. Truesdell (Cons)	L. Quijano

II. Review of New Proposed Joint Studies (1993)

1. Slim-hole drilling	J. Dunn (SNL)	??
2. H_2S Abatement	G. Horton (Unocal)	B. Terrazas
3. Seismic Surveying	??	??
4. Silica brick manufacture	E. Yearsley (CECI)	??
5. Cerro Prieto: Modeling	M. Shook (INEL) E. Yearsley (CECI) B. Barker (Unocal)	M. Ribo

III. Suggestions for New Joint Studies (1994)

IV. 26 January 94 am

Meeting between Principal Investigators of the Joint Projects to prepare plans for 1994 efforts and Summary Reports (1-2 pages) of the current status of the joint study.

DOECFE.pln

M E M O R A N D U M

TO: P.M. Wright

FROM: H.P. Ross

SUBJECT: Modifications to Existing DOE-CFE Agreement for Joint Geothermal Research, Next Five Years

DATE: January 31, 1994

Ted Mock requested a program plan for the next round of DOE-CFE geothermal research. He wants to recieve this from U S research groups by the end of February. Here is my input, written while the discussions are still fairly fresh.

CFE asked for specific help from UURI in three areas: geophysical interpretation for the Ceboruco area; geologic (& fluid inclusion) studies by Joe Moore; and advice and recommendations for developing a remote sensing capability. UURI may be able to modify its existing agreement with CFE to include these study topics.

1. Geophysical Interpretations for Ceboruco

Background

Francisco Arrellano described the Ceboruco area as an exploration area of 30-40 km (N-S) by 40-50 km (E-W) which includes the intersection of the northwest-trending Sierra Madre Occidental with the east-trending Neovolcanic Belt, in western Mexico. This reconnaissance area includes recent volcanoes and thermal springs with temperatures as high as 43 C. CFE acquired regional gravity and aeromagnetic coverage for this region, and then cotracted to EMI to acquire 90 MT sites well distributed throughout the area. TDEM data (Geonics 47 and 37) was also recorded at the MT sites but as much as 25 percent of these data are considered to be poor quality. The MT data are available in the GEOTOOLS package (Arnold Orange et al.) format. Following inversion of the MT data, two areas of thick conductive zones were identified. A drill hole to 1800 m located on the flanks of a young volcano penetrated a shallow aquifer (45 C) and recorded a maximum temperature of 62 C at depth. Other drill holes to lesser depths were also disappointing to CFE. CFE considers a reinterpretation of the MT data, (and this exploration program as a whole) their highest priority for UURI to address.

Project Plan

Limited funding is available for this and other CFE research, and Phil Wannamaker's time is already tightly scheduled. Therefore I propose the following plan.

1. CFE will first submit gravity, aeromagnetic, geologic, and other data to UURI in hardcopy for review and study.

2. UURI will complete a preliminary review of these data, form an initial evaluation, and perhaps identify specific MT and TDEM data for reinterpretation.

3. CFE will select key digital data and other additional information, and bring these to UURI.

4. A principal CFE geophycisit will spend one to two weeks at UURI reviewing MT and TDEM results with Phil Wannamaker in detail, and complete new 1-D (and 2-D, if practical) inversions to address any problems with earlier interpretations.

5. CFE and UURI geophysicists will prepare a preliminary draft report of these studies and their results at UURI, and complete the report at their respective institutions, corresponding as necessary.

2. Geologic Studies, Tres Virgenes

(to be addressed by Joe Moore)

3. Remote Sensing Studies

CFE scientists are interested in developing a remote sensing capability for use in reconaissance geothermal exploration. Ingr. Luis Quijano indicated that CFE would be interested in purchasing equipment for a remote sensing laboratory, if the cost was not excessive (i.e. much greater than $10,000), and would need UURI help and recommendations. Since the cost of a fully operational facility would certainly exceed this we proposed an alternate approach for remote sensing, as noted below.

1. CFE geologists will identify one or more areas of principal interest for a remote sensing study.

2. CFE will describe the selected areas to UURI, indicating latitudes and longitudes, and UURI (Greg Nash) will determine the availability, quality, and cost of such data. It is also possible to request new data acquisition on future saatellite passes. UURI will respond to CFE with this information.

3. CFE will request (or obtain directly) one or more data sets.

4. CFE will send one (or more) scientists to UURI to work with CRSC personnel on the processing and interpretation of one (or more) data sets.

5. CFE and UURI scientists will draft and then complete a report describing the data, the processing and the interpretation results of this remote sensing study.

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
15 FEBRUARY 1994

GEOPHYSICAL STUDIES
CEBORUCO GEOTHERMAL RECONNAISSANCE AREA

Phillip E. Wanamaker
Howard P. Ross
UURI
DOE

Jose Francisco Arellano Guadarrama
Senior Geophysicist
Gerencia
CFE

Background:

UURI and CFE completed cooperative geophysical studies of the Los Azufres geothermal area in an earlier DOE-CFE Cooperative Agreement, and these were reported in the 1989 DOE-CFE Research Proceedings. The Ceboruco area, within the western Neovolcanic Belt, was identified as a promising geothermal area for additional geophysical studies during the 1989-1994 agreement. CFE completed extensive gravity, aeromagnetic, and magnetotelluric (MT) studies in the greater Ceboruco area (30-40 km N-S by 40-50 km E-W) but UURI was unable to participate due to lack of project funding. Initial drilling results, including a test hole 1800 m deep sited on MT results, have been disappointing and CFE geophysicists have requested a review of contractor geophysical data, interpretations, and exploration strategy.

Objective:

This joint study will review the exploration strategy in general, and the MT data and interpretation in particular in the prospective western Neovolcanic Belt. The identification of any problem areas will improve exploration results within this province, and perhaps the Cascades in the western United States.

Program for 1994:

To proceed in this research with the most efficiency, CFE will first submit gravity, aeromagnetic, geologic, MT, TDEM and other data in hardcopy for UURI review and study. UURI will complete a preliminary data review and identify specific MT data for reinterpretation. CFE will select key digital data and supporting information and bring these to UURI. A CFE geophysicist will spend one to two weeks at UURI reviewing MT data with Phil Wannamaker and completing new 1-D (and 2-D, if practical) interpretations. CFE and UURI geophysicists will complete a report describing new results and recommendations for future studies and improved exploration efforts.

DOE-CFE GEOTHERMAL AGREEMENT

Second Technical Meeting
25-26 January 1994
Mexicali, B.C.

Expected DOE Attendance
(as of 21Jan94)

DOE	John E. Mock
CECI	Elliot Yearsley
INEL	Joel Renner
	Mike Shook
LBL	Marcelo Lippmann
	Al Truesdell (Cons.)
S-Cubed	Sabodh Gay
SGP	Marc Fioravanti
	Paul Kruger
SNL	Jim Dunn
Unocal	Ben Barker
	Glen Horton
UURI	Joe Moore
	Greg Nash
	Howard Ross

U S THERMAL METHODS RESEARCHERS

Dr. David D. Blackwell
Professor of Geophysics
Southern Methodist University
Department of Geological Sciences
Dallas, Texas 75275-0001

Phone: (214) 768-2745
FAX: (214) 768-4289

Dr. William D. Gonsold
Professor
Department of Geology and Geological Engineering
P.O. Box 8068, University Station
Grand Forks, North Dakota 58202

Phone: (701) 777-2631
FAX: (701) 777-4838

Dr. Henry P. Heassler
Professor
Department of Geology and geophysics
P.O. Box 3006
Laramie, Wyoming 82071-3006

Phone: (307) 766-3278
FAX: (307) 766-6679

Dr. John H. Sass
Geophysicist
United States Department of the Interior
Geological Survey
Geothermal Studies Project
2255 North Gemini Drive
Flagstaff, Arizona 86001

Phone: (602) 556-7000
FAX: (602) 556-7169

Instrumentation:

N.P. Instrument Co.
Attn. Bob Spafford
6234 Glendora Ave.
Dallas, Texas 75230

(Note: Address may have changed. Can contacted through Dr. David Blackwell at Southern Methodist Univ., Texas)

Phone: (214) 768-4224 SMU
(214) 361-1307 home

UNIVERSITY OF UTAH RESEARCH INSTITUTE
GEOPHYSICAL RESEARCH AND STUDIES

Magnetotelluric (MT) and CSAMT Research

- Instrumentation Development
- Geothermal and Crustal Field Studies
- Computer Algorithm Development

Philip E. Wannamaker
John A. Stodt
Field Technicians

Borehole Electrical Geophysics

- Computer Algorithm Development
- Field Instrumentation System
- Preliminary Field Test (shallow)
- Geothermal Field Test
- Test Algorithms and Interpretation

Phillip M. Wright
Phillip E. Wannamaker
John A. Stodt
Alan C. Tripp
Graduate Students

Self-Potential Method

- Field Studies for Characterization
- Field Technique Development
- Interpretation

Howard P. Ross
Robert E. Blackett (UGS)
James C. Witcher (NMSU)

Newcastle, Utah Temperature Monitoring

- Monthly Temperature Monitoring
- Interpretation and Reporting
- Sustainable Development

Howard P. Ross
Robert E. Blackett (UGS)

Other Geophysical Studies

- Gravity and Magnetic Interpretation
- Electrical Resistivity Interpretation
- Field Studies as Required
- Computer Program Conversion, Acquisition

UNIVERSITY OF UTAH RESEARCH INSTITUTE

GEOPHYSICAL RESEARCH AND STUDIES

MAGNETOTELLURIC (MT) AND CSAMT RESEARCH

* Instrumentation Development
* Geothermal and Crustal Field Studies
* Computer Algorithm Development

Philip E. Wannamaker
John A. Stodt
Field Technicians

BOREHOLE ELECTRICAL GEOPHYSICS

* Computer Algorithm Development
* Field Instrumentation System
* Preliminary Field Test (shallow)
* Geothermal Field Test
* Test Algorithms and Interpretation

Phillip M. Wright
Phillip E. Wannamaker
John A. Stodt
Alan C. Tripp
Graduate Students

SELF-POTENTIAL METHOD

* Field Studies for Characterization
* Field Technique Development
* Interpretation

Howard P. Ross
Robert E. Blackett (UGS)
James C. Witcher (NMSU)

NEWCASTLE, UTAH TEMPERATURE MONITORING

* Monthly Temperature Monitoring
* Interpretation and Reporting
* Sustainable Development

Howard P. Ross
Robert E. Blackett (UGS)

OTHER GEOPHYSICAL STUDIES

* Gravity and Magnetic Interpretation
* Electrical Resistivity Interpretation
* Field Studies as Required
* Computer Program Conversion, Acquisition

UURI - CFE SLIDES DISCUSSION

1 Geothermal Geophysical Research

2 Schematic diagram portraying operational modes of UURI field MT instrument. Modes include 7-channel standard base-remote setup, 10-channel dual-site collection, and 4-channel E-field profiling with 3-channel base h-field unit and remote reference.

3 Locations of regional MT transect programs funded mainly by the National Science Foundation. UURI is P I in EMSLAB, RUBY, CH, SEA, and ANTALITH.

4 Eastern Great Basin MT transect: Southern Cordilleran hingelin of Utah and Nevada: Roosevelt HS on the east. 50+ stations, 160 km.

5 2-D numerical model interpretation to depths of 12 km, fairly well defined to depths of 5 km. Deep conductors.

6 Regional geologic map of Valles Caldera, NM showing locations of survey CSAMT layout. Crossed-bipole (2 km) antenna are 13 km SSW of corehole VC-2B and Sulphur Springs.

7 Best-fit 2-D resistivity model of central W-E line across VC-2B well site. Depths > 2km.

8 Example of earth model with topography discretized by elements, by algorithm IP2D1.

9 Generalized model of a geothermal system with well to side (a drill miss) and schematic borehole resistivity layout.

10 Conceptual model for cross-borehole and borehole to surface surveys.

11 UURI borehole geophysics truck. First survey completed in 1993, now being interpreted.

12 Truck interior, winch with 3,500 ft (1,200 m) logging cable rated to 250 C. Zonge transmitter, 6 channel receiver.

13 Self-Potential Method.

14 S P Method, ground layout.

15 Newcastle, Utah covered geothermal area, resistivity lines.

16 Dipole-dipole resistivity profile, a=150 m. Note 4 ohm-m.
17 Newcastle SP anomaly, -110 mV. Elongate along fault.
18 Spoke layout at Woods Ranch, between 26C, 34C drill holes.
19 Woods Ranch SP survey, -60 mV anomaly.

UURI - CFE SLIDES DISCUSSION

✓1 Geothermal Geophysical Research

✓2 Schematic diagram portraying operational modes of UURI field MT instrument. Modes include 7-channel standard base-remote setup, 10-channel dual-site collection, and 4-channel E-field profiling with 3-channel base h-field unit and remote reference.

✓3 Locations of regional MT transect programs funded mainly by the National Science Foundation. UURI is P I in EMSLAB, RUBY, CH, SEA, and ANTALITH.

✓4 Eastern Great Basin MT transect: Southern Cordilleran hingelin of Utah and Nevada: Roosevelt HS on the east. 50+ stations, 160 km.

✓5 2-D numerical model interpretation to depths of 12 km, fairly well defined to depths of 5 km. Deep conductors.

6 Regional geologic map of Valles Caldera, NM showing locations of survey CSAMT layout. Crossed-bipole (2 km) antenna are 13 km SSW of corehole VC-2B and Sulphur Springs.

7 Best-fit 2-D resistivity model of central W-E line across VC-2B well site. Depths > 2km.

8 Example of earth model with topography discretized by elements, by algorithm IP2D1.

✓9 Generalized model of a geothermal system with well to side (a drill miss) and schematic borehole resistivity layout.

✓10 Conceptual model for cross-borehole and borehole to surface surveys.

✓11 UURI borehole geophysics truck. First survey completed in 1993, now being interpreted.

12 Truck interior, winch with 3,500 ft (1,200 m) logging cable rated to 250 C. Zonge transmitter, 6 channel receiver.

13 Self-Potential Method.

✓14 S P Method, ground layout.

✓15 Newcastle, Utah covered geothermal area, resistivity lines.

✓16 Dipole-dipole resistivity profile, a=150 m. Note 4 ohm-m.
17 Newcastle SP anomaly, -110 mV. Elongate along fault.
✓18 Spoke layout at Woods Ranch, between 26C, 34C drill holes.
19 Woods Ranch SP survey, -60 mV anomaly.

UNIVERSITY OF UTAH RESEARCH INSTITUTE

GEOPHYSICAL RESEARCH AND STUDIES

MAGNETOTELLURIC (MT) AND CSAMT RESEARCH

* Instrumentation Development	Philip E. Wannamaker
* Geothermal and Crustal Field Studies	John A. Stodt
* Computer Algorithm Development	Field Technicians

BOREHOLE ELECTRICAL GEOPHYSICS

* Computer Algorithm Development	Phillip M. Wright
* Field Instrumentation System	Phillip E. Wannamaker
* Preliminary Field Test (shallow)	John A. Stodt
* Geothermal Field Test	Alan C. Tripp
* Test Algorithms and Interpretation	Graduate Students

SELF-POTENTIAL METHOD

* Field Studies for Characterization	Howard P. Ross
* Field Technique Development	Robert E. Blackett (UGS)
* Interpretation	James C. Witcher (NMSU)

NEWCASTLE, UTAH TEMPERATURE MONITORING

* Monthly Temperature Monitoring	Howard P. Ross
* Interpretation and Reporting	Robert E. Blackett (UGS)
* Sustainable Development	

OTHER GEOPHYSICAL STUDIES

* Gravity and Magnetic Interpretation
* Electrical Resistivity Interpretation
* Field Studies as Required
* Computer Program Conversion, Acquisition

UNIVERSITY OF UTAH RESEARCH INSTITUTE
GEOPHYSICAL RESEARCH AND STUDIES

Magnetotelluric (MT) and CSAMT Research

- Instrumentation Development
- Geothermal and Crustal Field Studies
- Computer Algorithm Development

Philip E. Wannamaker
John A. Stodt
Field Technicians

Borehole Electrical Geophysics

- Computer Algorithm Development
- Field Instrumentation System
- Preliminary Field Test (shallow)
- Geothermal Field Test
- Test Algorithms and Interpretation

Phillip M. Wright
Phillip E. Wannamaker
John A. Stodt
Alan C. Tripp
Graduate Students

Self-Potential Method

- Field Studies for Characterization
- Field Technique Development
- Interpretation

Howard P. Ross
Robert E. Blackett (UGS)
James C. Witcher (NMSU)

Newcastle, Utah Temperature Monitoring

- Monthly Temperature Monitoring
- Interpretation and Reporting
- Sustainable Development

Howard P. Ross
Robert E. Blackett (UGS)

Other Geophysical Studies

- Gravity and Magnetic Interpretation
- Electrical Resistivity Interpretation
- Field Studies as Required
- Computer Program Conversion, Acquisition

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-584-4422

January 17, 1994

Ingr. Jose Francisco Arellano Guadarrama
Jefe, Ofna. De Geofisica
Departmento De Exploracion
Comision Federal De Electricidad
Gerencia De Proyectos Geothermoelectricos
Morelia, Michoacan
Mexico

Dear Jose:

Dr. Mike Wright asked me to respond to your FAX of January 3, 1994. Mike sends his best wishes, and regrets that he will not be able to attend the meeting to discuss a new research and development agreement between the US DOE and CFE. Instead, Mike has asked that Dr. Joseph Moore (Section Manager, Geochemistry), Greg Nash (Section Manager, Remote Sensing), and I attend the meeting on behalf of UURI.

In reviewing your letter I understand that there is a new interest in addressing specific exploation and development problems instead of a general exploration program. You list a large number of specific problems, some of which could be very difficult and challenging. The UURI geophysics staff is small, and I understanding that funding for the UURI-CFE work may be rather limited. Thus we will probably only be able to address a few problems for the first few years of the agreement. I encourage you to establish a priority list for those problem areas which you consider most important for UURI to study with CFE.

Although all of the CFE problem areas seem interesting, UURI would be best prepared to address gravity, magnetic and electrical data modeling and interpretation. We do not have an active capability for potiential field continuation from irregular surfaces, and some other groups may be more experienced in passive seismic studies (i.e. LBL). Our remote sensing group may be able to address several problems in remote sensing. I will bring some information on researchers doing current work on thermal modeling and gradient hole interpretation.

Mr. Greg Nash will be prepared to indicate the UURI capabilities in Remote Sensing and Geographic Information Systems (GIS). I will be able to indicate the current UURI geophysical research program.

U S THERMAL METHODS RESEARCHERS

Dr. David D. Blackwell
Professor of Geophysics
Southern Methodist University
Department of Geological Sciences
Dallas, Texas 75275-0001

Phone: (214) 768-2745
FAX: (214) 768-4289

Dr. William D. Gonsold
Professor
Department of Geology and Geological Engineering
P.O. Box 8068, University Station
Grand Forks, North Dakota 58202

Phone: (701) 777-2631
FAX: (701) 777-4838

Dr. Henry P. Heassler
Professor
Department of Geology and geophysics
P.O. Box 3006
Laramie, Wyoming 82071-3006

Phone: (307) 766-3278
FAX: (307) 766-6679

Dr. John H. Sass
Geophysicist
United States Department of the Interior
Geological Survey
Geothermal Studies Project
2255 North Gemini Drive
Flagstaff, Arizona 86001

Phone: (602) 556-7000
FAX: (602) 556-7169

Instrumentation:

N.P. Instrument Co.
Attn. Bob Spafford
6234 Glendora Ave.
Dallas, Texas 75230

(Note: Address may have changed. Can contacted through Dr. David Blackwell at Southern Methodist Univ., Texas)

Phone: (214) 768-4224 SMU
(214) 361-1307 home

UNIVERSITY OF UTAH RESEARCH INSTITUTE
GEOPHYSICAL RESEARCH AND STUDIES

Magnetotelluric (MT) and CSAMT Research

• Instrumentation Development	Philip E. Wannamaker
• Geothermal and Crustal Field Studies	John A. Stodt
• Computer Algorithm Development	Field Technicians

Borehole Electrical Geophysics

• Computer Algorithm Development	Phillip M. Wright
• Field Instrumentation System	Phillip E. Wannamaker
• Preliminary Field Test (shallow)	John A. Stodt
• Geothermal Field Test	Alan C. Tripp
• Test Algorithms and Interpretation	Graduate Students

Self-Potential Method

• Field Studies for Characterization	Howard P. Ross
• Field Technique Development	Robert E. Blackett (UGS)
• Interpretation	James C. Witcher (NMSU)

Newcastle, Utah Temperature Monitoring

• Monthly Temperature Monitoring	Howard P. Ross
• Interpretation and Reporting	Robert E. Blackett (UGS)
• Sustainable Development	

Other Geophysical Studies

- Gravity and Magnetic Interpretation
- Electrical Resistivity Interpretation
- Field Studies as Required
- Computer Program Conversion, Acquisition

UURI - CFE SLIDES DISCUSSION

1 Geothermal Geophysical Research

2 Schematic diagram portraying operational modes of UURI field MT instrument. Modes include 7-channel standard base-remote setup, 10-channel dual-site collection, and 4-channel E-field profiling with 3-channel base h-field unit and remote reference.

3 Locations of regional MT transect programs funded mainly by the National Science Foundation. UURI is P I in EMSLAB, RUBY, CH, SEA, and ANTALITH.

4 Eastern Great Basin MT transect: Southern Cordilleran hingelin of Utah and Nevada: Roosevelt HS on the east. 50+ stations, 160 km.

5 2-D numerical model interpretation to depths of 12 km, fairly well defined to depths of 5 km. Deep conductors.

6 Regional geologic map of Valles Caldera, NM showing locations of survey CSAMT layout. Crossed-bipole (2 km) antenna are 13 km SSW of corehole VC-2B and Sulphur Springs.

7 Best-fit 2-D resistivity model of central W-E line across VC-2B well site. Depths > 2km.

8 Example of earth model with topography discretized by elements, by algorithm IP2D1.

9 Generalized model of a geothermal system with well to side (a drill miss) and schematic borehole resistivity layout.

10 Conceptual model for cross-borehole and borehole to surface surveys.

11 UURI borehole geophysics truck. First survey completed in 1993, now being interpreted.

12 Truck interior, winch with 3,500 ft (1,200 m) logging cable rated to 250 C. Zonge transmitter, 6 channel receiver.

13 Self-Potential Method.

14 S P Method, ground layout.

15 Newcastle, Utah covered geothermal area, resistivity lines.

16 Dipole-dipole resistivity profile, a=150 m. Note 4 ohm-m.
17 Newcastle SP anomaly, -110 mV. Elongate along fault.
18 Spoke layout at Woods Ranch, between 26C, 34C drill holes.
19 Woods Ranch SP survey, -60 mV anomaly.

UURI - CFE SLIDES DISCUSSION

1 Geothermal Geophysical Research

2 Schematic diagram portraying operational modes of UURI field MT instrument. Modes include 7-channel standard base-remote setup, 10-channel dual-site collection, and 4-channel E-field profiling with 3-channel base h-field unit and remote reference.

3 Locations of regional MT transect programs funded mainly by the National Science Foundation. UURI is P I in EMSLAB, RUBY, CH, SEA, and ANTALITH.

4 Eastern Great Basin MT transect: Southern Cordilleran hingelin of Utah and Nevada: Roosevelt HS on the east. 50+ stations, 160 km.

5 2-D numerical model interpretation to depths of 12 km, fairly well defined to depths of 5 km. Deep conductors.

6 Regional geologic map of Valles Caldera, NM showing locations of survey CSAMT layout. Crossed-bipole (2 km) antenna are 13 km SSW of corehole VC-2B and Sulphur Springs.

7 Best-fit 2-D resistivity model of central W-E line across VC-2B well site. Depths > 2km.

8 Example of earth model with topography discretized by elements, by algorithm IP2D1.

9 Generalized model of a geothermal system with well to side (a drill miss) and schematic borehole resistivity layout.

10 Conceptual model for cross-borehole and borehole to surface surveys.

11 UURI borehole geophysics truck. First survey completed in 1993, now being interpreted.

12 Truck interior, winch with 3,500 ft (1,200 m) logging cable rated to 250 C. Zonge transmitter, 6 channel receiver.

13 Self-Potential Method.

14 S P Method, ground layout.

15 Newcastle, Utah covered geothermal area, resistivity lines.

16 Dipole-dipole resistivity profile, a=150 m. Note 4 ohm-m.
17 Newcastle SP anomaly, -110 mV. Elongate along fault.
18 Spoke layout at Woods Ranch, between 26C, 34C drill holes.
19 Woods Ranch SP survey, -60 mV anomaly.

UNIVERSITY OF UTAH RESEARCH INSTITUTE

GEOPHYSICAL RESEARCH AND STUDIES

MAGNETOTELLURIC (MT) AND CSAMT RESEARCH

* Instrumentation Development
* Geothermal and Crustal Field Studies
* Computer Algorithm Development

Philip E. Wannamaker
John A. Stodt
Field Technicians

BOREHOLE ELECTRICAL GEOPHYSICS

* Computer Algorithm Development
* Field Instrumentation System
* Preliminary Field Test (shallow)
* Geothermal Field Test
* Test Algorithms and Interpretation

Phillip M. Wright
Phillip E. Wannamaker
John A. Stodt
Alan C. Tripp
Graduate Students

SELF-POTENTIAL METHOD

* Field Studies for Characterization
* Field Technique Development
* Interpretation

Howard P. Ross
Robert E. Blackett (UGS)
James C. Witcher (NMSU)

NEWCASTLE, UTAH TEMPERATURE MONITORING

* Monthly Temperature Monitoring
* Interpretation and Reporting
* Sustainable Development

Howard P. Ross
Robert E. Blackett (UGS)

OTHER GEOPHYSICAL STUDIES

* Gravity and Magnetic Interpretation
* Electrical Resistivity Interpretation
* Field Studies as Required
* Computer Program Conversion, Acquisition

UNIVERSITY OF UTAH RESEARCH INSTITUTE

GEOPHYSICAL RESEARCH AND STUDIES

MAGNETOTELLURIC (MT) AND CSAMT RESEARCH

* Instrumentation Development
* Geothermal and Crustal Field Studies
* Computer Algorithm Development

Philip E. Wannamaker
John A. Stodt
Field Technicians

BOREHOLE ELECTRICAL GEOPHYSICS

* Computer Algorithm Development
* Field Instrumentation System
* Preliminary Field Test (shallow)
* Geothermal Field Test
* Test Algorithms and Interpretation

Phillip M. Wright
Phillip E. Wannamaker
John A. Stodt
Alan C. Tripp
Graduate Students

SELF-POTENTIAL METHOD

* Field Studies for Characterization
* Field Technique Development
* Interpretation

Howard P. Ross
Robert E. Blackett (UGS)
James C. Witcher (NMSU)

NEWCASTLE, UTAH TEMPERATURE MONITORING

* Monthly Temperature Monitoring
* Interpretation and Reporting
* Sustainable Development

Howard P. Ross
Robert E. Blackett (UGS)

OTHER GEOPHYSICAL STUDIES

* Gravity and Magnetic Interpretation
* Electrical Resistivity Interpretation
* Field Studies as Required
* Computer Program Conversion, Acquisition

CEBORUCO MT STUDY

1. Figure 8 from Venegas and Arellano

2. Figure 9 from Venegas and Arellano

3. Long Valley color MT model
   -Altered tuff on top of Bishop Tuff was conductive caldera-wide. However hot water was encountered only in the west moat.

4. Upper right (east) portion of EMSLAB model for MT transect across the Cascade Range (Oregon). The altered Breitenbush Tuff is conductive but not economic for geothermal energy.

5. Figure 9 from Venegas and Arellano (repeat). Note anomalous areas of Copley and Orange.

6. Figure 6 of Copley and Orange
   -Exemplifies anomalous and non-anomalous behavior.
   -Pronounced TE minimum at mid-to-high frequencies, presumeably indicative of a conductive dike.

7. Figure 20 of Copley and Orange
   -Attempt to simulate anomalous responses
   -'Peaked' conductor may be a significant structure, or may be 'topography' on buried original conductive layer.

8. Figure 17 of Copley and Orange
   -Similar but with deep conductive substratum
   -Meant to represent occassionally-observed deeper layer (eg Fig. 2.)
   -Need for wide, deep base debatable since TE mode minimum most pronounced in vicinity of top of dike.

9-11. Profile locations for psuedosections, plus sections Marquesado-Coapan and Carillo Puerto-Ahucatlan
   -Actually, MT-24 is <u>not</u> very anomalous in the conductance of the presumed tuff, compared to MT-1 or MT-3.

DOE-CFE Geothermal Agreement

GEOPHYSICAL STUDIES
CEBORUCO GEOTHERMAL RECONNAISSANCE AREA

Philip E. Wannamaker and Howard P. Ross - UURI
J. F. Arellano G. - CFE

PROGRESS REPORT for 1994

Introduction

This project was suggested by CFE scientists at the second technical meeting, January 1994. The Ceboruco area, within the western Neovolcanic Belt, was identified as a promising geothermal area for additional geophysical studies during the 1989-1994 agreement. CFE completed extensive gravity, aeromagnetic, electrical resistivity and magnetotelluric (MT) studies in the greater Ceboruco reconnaissance area (approximately 1200 sq km) but UURI was unable to participate due to lack of project funding. Initial drilling results, including the 2800 m deep CB-1 were disappointing. Since the drill hole was sited in part on geophysical (MT, gravity) results, CFE requested a review of contractor geophsical data and interpretations. UURI has had a continuing interest in the geothermal exploration strategy and proposed a general review of the geophysical exploration effort.

Planned Scope of Project for 1994

The scope of the project for 1994 was to:

1. Review the Ceboruco exploration strategy.
2. Review supporting geologic and geophysical data.
3. Review and critique MT data and interpretation.
4. Complete new MT modeling and interpretation, as needed.

Results to Date

CFE scientists transmitted an extensive geologic and geophysical database to UURI. The geologic studies provided necessary background for the understanding and interpretation of the geophysical data, and for an understanding of the exploration strategy. UURI scientists reviewed the various reports and data.

Dr. Wannamaker completed a detailed review of the MT reports and data completed by GeoEvaluaciones. He found the treatment and evaluation of the data to be competent, and the interpretation generally valid. The occurrence of conductive volcanic horizons has been noted at Long Valley, California, and in the Cascades in the Pacific northwest, and these occurrences have presented severe interpretation and exploration problems in these areas also. Dr. Wannamaker has identified some additional concerns with MT data interpretations in these environments. The

MT contractor computed appropriate two-dimensional (2-D) models, and new numerical modeling was not deemed necessary. UURI was unable to obtain the necessary software in time to use the GEOTOOLS formated MT data submitted by CFE.

A second interpretation of the MT data was completed by CFE geophysicists. This interpretation called attention to several MT stations SW of Ceboruco volcano which suggested a larger conductivity-thickness body at depth. These stations had not been identified by GeoEvaluaciones as a promising target area because they did not exhibit a response typical of conductive bodies going to depth, and were believed to be part of the region-wide conductive horizon. Decreases in apparent resistivity observed for periods longer than 1 to 10 seconds are due to the regional, mid-crustal state, with some short scale data variations caused by minor static shifts, or data noise.

Dr. Ross reviewed the aeromagnetic and gravity data, and noted that extensive state-of-the-art processing had been applied to the aeromagnetic data. A final, geometric interpretion of magnetic bodies and geologic structures was not noted, however.

The gravity survey is described as a reconnaissance level survey which probably was restricted to existing roads and trails. The locations of gravity stations were determined by vehicle odometer (+/- 100 m), and station elevations were estimated from contour maps (estimated to be +/-10 m). It does not appear that terrain corrections were applied to the data, and these could be quite significant (1-3 mGal, 10-30 g.u.) near Ceboruco volcano. Elevation errors could result in errors of as much as 2.2 mGals (22 g.u.). Another limitation of the Bouguer gravity map, especially in the area near CB-1, is the relatively low data density. Although the automated contour interpolation routine may provide the best estimate of gravity contours, it <u>could</u> lead to considerable error in areas of low data density, especially when using data which may be in error due to elevation errors and without terrain corrections. Thus the gravity map may be useful in projecting regional geologic features, but may be inappropriate for use in drill site selection.

Plans for 1995

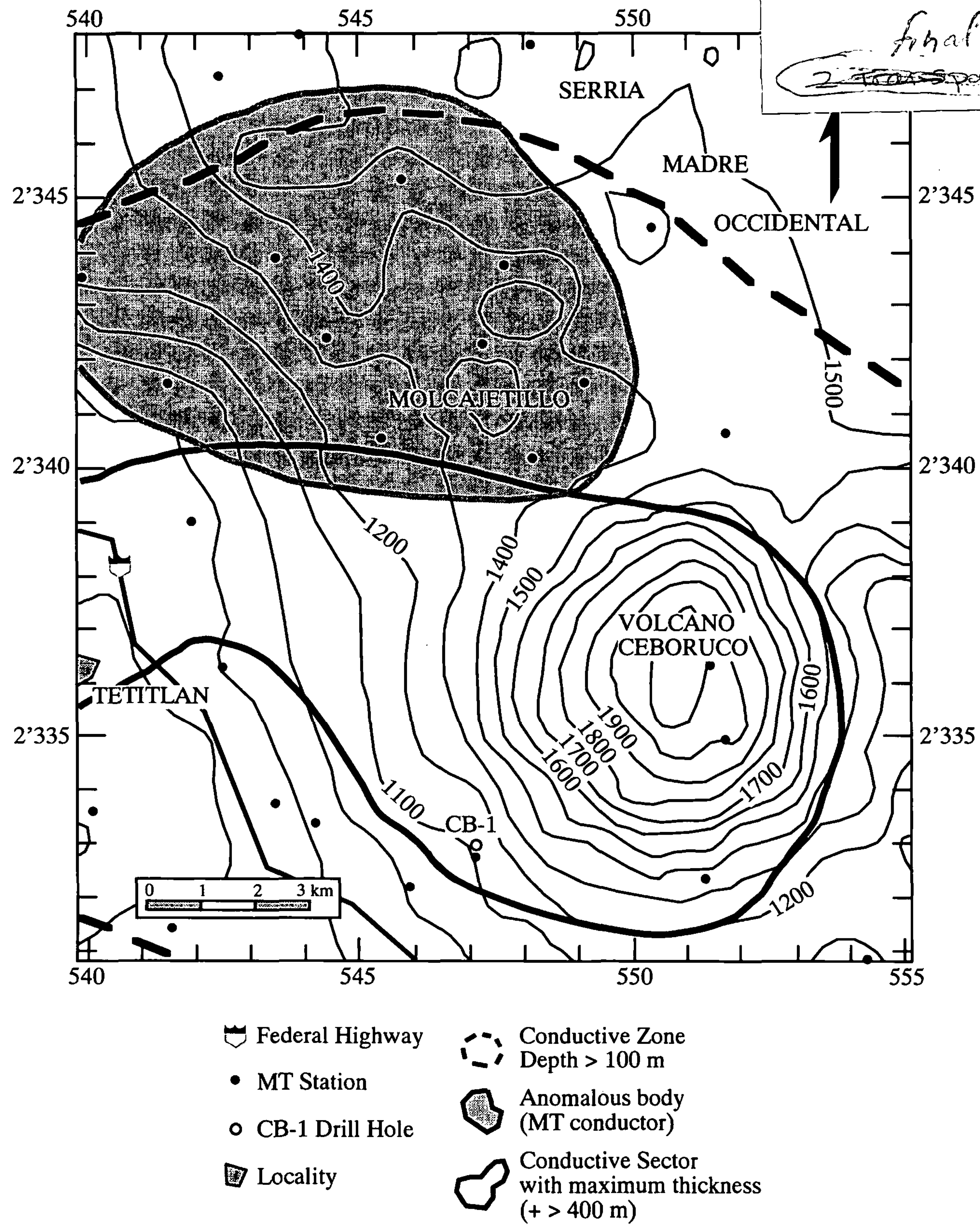
1. Additional detailed MT interpretation could be undertaken if specific interpretation problems are identified by CFE geophysicists, such as evaluating proposed drill targets.

2. UURI suggests a detailed evaluation of the accuracy of the Bouguer gravity map for an area of approximately 100 sq km, including the large gravity low which extends southwest from Ceboruco volcano. Gravity data should be obtained at 25 to 50 stations, well distributed between the existing stations. Positions and elevations should be accurately determined for these and nearby existing stations (GPS control?) and full terrain corrections should be applied.

ORIG

final

~~2 transpars~~



Ceboruco Area - MT and Resistivity Results [illegible] CB-3 [illegible]

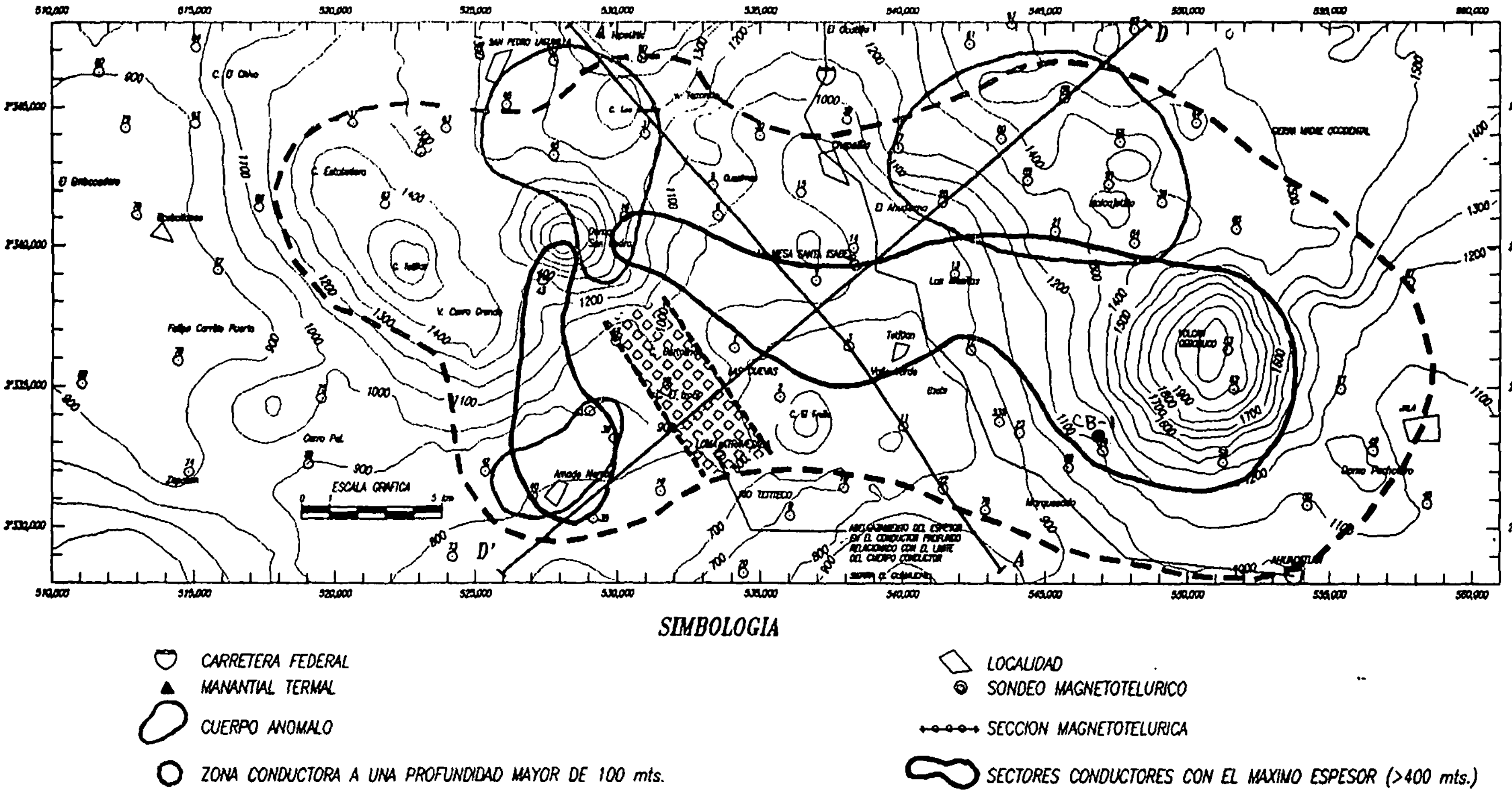


FIGURA 8.- SECTORES GEOELECTRICAMENTE ANOMALOS DE ACUERDO CON LOS DATOS MAGNETOTELURICOS

FIRST RESULTS OF DEEP EXPLORATORY DRILLING IN THE EL CEBORUCO GEOTHERMAL ZONE

J. Cesar Viggiano-Guerra and Luis C.A. Gutierrez-Negrin
Comision Federal de Electricidad, Alejandro Volta 655
Morelia, Mich., Mexico, C.P. 58290

ABSTRACT

Geological, geochemical, and geophysical studies have been made by the Comisión Federal de Electricidad (CFE) in the El Ceboruco Volcano geothermal zone. In order to complete its preliminary geothermal assessment before deep drilling, some shallow gradient wells were drilled and measured in this zone. The first deep exploratory well was recently completed to 2,800 meters depth. This deep well did not present high temperatures (maximum 112°C) nor important hydrothermal alteration at depth, meaning that the probable geothermal system is more restricted than anticipated.

Introduction

Over the past 10 years, the El Ceboruco Volcano, and the San Pedro Dome geothermal zones have been explored by the Comisión Federal de Electricidad (CFE: Federal Commission for Electricity) exploration staff. In addition to geological mapping, geochemical fluids analysis, geophysical surveys (including resistivity, magnetotelluria, gravimetry and magnetometry), and a number of shallow gradient wells were drilled to accomplish the exploration. More priority was given to the El Ceboruco area because of the volcanological evolution, structural framework, and apparent geothermal possibilities. As a result, a deep exploratory well, named CB-1, was drilled by end of 1993, and the beginning of 1994 to 2,800 meters depth.

In this paper we attempt to provide a short and preliminary synthesis of the lithological, mineralogical, and geothermal results of the well CB-1, as well as to sketch some useful lessons, especially concerning the hydrothermal mineralogy interpretation focused in further exploration in the zone.

Regional Geological Setting

The El Ceboruco Volcano, together with other Quaternary volcanic centers, is located at the western part of the Mexican Volcanic Belt (Figure 1), whose Plio-Quaternary calcalkaline activity is related to the subduction of the Cocos Plate beneath the North-American Plate, and to the aseismic and waning Rivera Plate, under the Jalisco Block along the Middle American Trench (Luhr et al., 1985). This process seems to be responsible of the volcanism at this place.

In addition, a triple junction apparently ocurrs 50 km southernly from Guadalajara City (Figure 1) as a consequence of that tectonic process, with a rather complicated evolution which includes the Chapala Graben toward the east, the Tepic-Zacoalco Graben in the northwest and the Colima Graben to the south (Luhr et al., 1985; Stock, 1993).

Locally, the El Ceboruco Volcano lies entirely on the northwestern portion of the Tepic-Zacoalco Graben, which seems to be an ongoing rifting zone since Pliocene (Luhr et al., 1985). Small volumes of unusual alkaline magmas have erupted in this graben, in close association with more abundant subduction-related calcalkaline magmas erupted by andesitic stratovolcanoes, like the El Ceboruco itself.

Alkaline magmas are varieties found in zones of active rifting elsewhere in the world. At the Tepic-Zacoalco Graben, their true origin, according to Luhr et al. (1985), may be due to the spreading ridge jumping which is being propagated at approximately about 10 to 12 million years ago from the South Pacific Rise in different stages. So, the East Pacific Rise segment bounded by the Rivera and Tamayo fracture zones, would be current in the process of jumping some 600 km eastward, to the site of the Colima Graben, thus, continuing the northward propagation of the ridge-segment jumps (see insert in Figure 1).

The El Ceboruco Volcano

Understanding of history of the El Ceboruco Volcano is a very important matter in order to better know the geothermal potential of the area. Nelson (1986) has carried out an exhaustive study of this volcano, focused on the volcanological mapping and petrological studies.

El Ceboruco is a middle-size stratovolcano, with 60 km^3 in volume; it is the only volcano with historic activity in this portion of the Mexican Volcanic Belt. Its eruptive history can

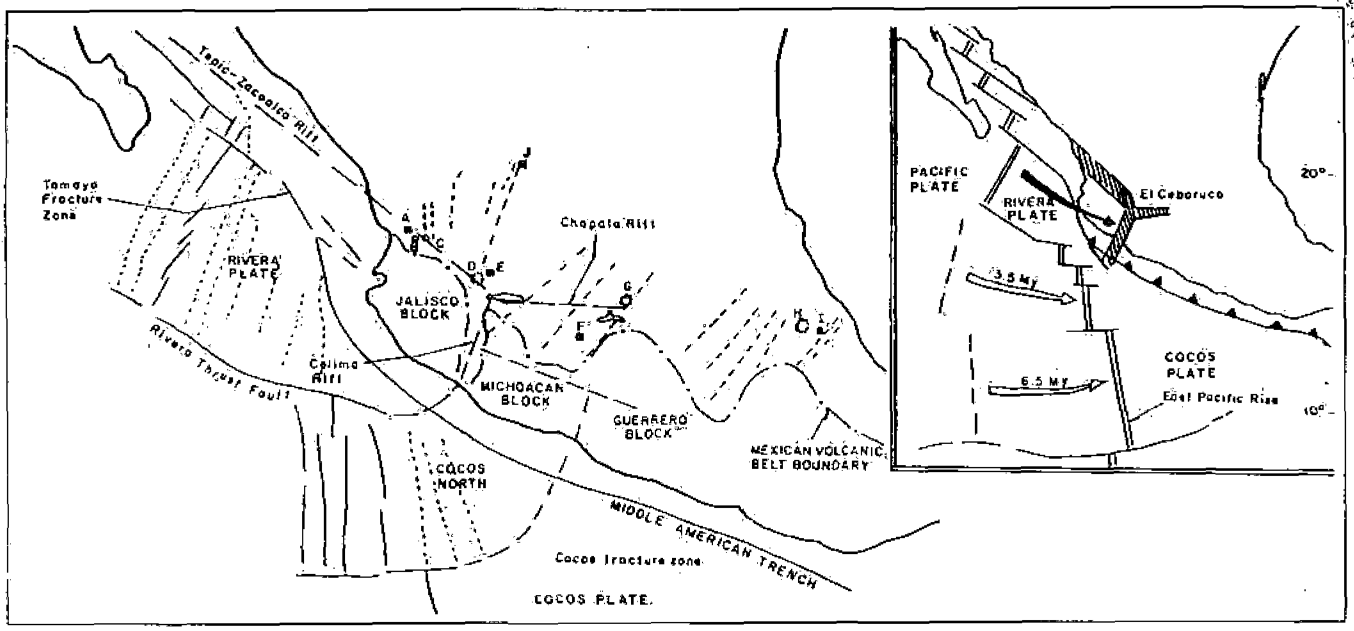


Figure 1. El Ceboruco regional tectonic framework: **LEGEND:** A. Tepic City, B. Sangangüey Volcano, C. El Ceboruco Volcano, D. La Primavera Caldera, E. Guadalajara City, F. Morelia City, G. Los Azufres, H. Los Humeros Caldera, I. Jalapa City, J. Zacatecas City. **INSERT** : Active rifting (dashed zone) as a result of a present spreading ridge-jumping. *(Data from Luhr et al., 1985, and Stock, 1993).*

be divided into three stages, which are included in Table 1 (after data from Nelson, 1986, and Romero and Palma, 1993).

Based upon the magma evolution, Nelson (1986) suggests the volcano could now be evolving toward a gass-bearing composition richer in SiO_2, and could erupt in coming days. He has estimated that there were at least eigth eruptions over the last 1,000 years. The last eruption which took place in 1870, left a thick (200 meters) dacitic flow on the southwestern flank of the volcano, a new eruptive event could happen in the next several years.

However, the volcanic history of the El Ceboruco Volcano makes it very feasible that the magmatic chamber of the volcano is at a depth and contains conditions to behave as a heat source for the probable geothermal system beneath it.

Exploratory Studies Prior Drilling

In addition to usual geological mapping, regional tectonic, and structural studies, geophysical surveys, with special emphasis on magnetotelluric and gravimetric studies, were achieved as in the El Ceboruco zone as in the Tepic-Zacoalco Graben. Magnetotelluric survey in El Ceboruco reported apparent important low resistivity anomalies located beneath the volcano and in two other areas. These anomalies were believed to be associated with the geothermal aquifer (Romero and Palma, 1993).

On the other hand, interpretation of the Bouguer Anomaly suggested a lithological basement underlaying those volcanic rocks belonging to El Ceboruco, that could represent rocks of the Tertiary Sierra Madre Occidental (SMO). The SMO is the largest ignimbritic province in the world, and outcrops about 4 km northeasternly of the El Ceboruco Volcano. An echelon fault array, dipping to the southwest and affecting rocks of the SMO, was interpretated. It was believed that these ignimbritic rocks could behave as a cap rock.

Geochemical analysis carried out in gases from fumaroles of the inner caldera and from the 1870 dacitic flow, point out the presence of both CO_2 and H_2S, being first the most abundant compound (Romero and Palma, 1993). Further data on fumaroles are also reported by Nelson (1986), with superficial temperatures ranging from 55°C to 92°C, making it the hottest related to the most recent flow (that of 1870).

Recently, a very small altered area, around 0.5 meters in diameter, located in the most recent crater, was sampled and studied by X Ray Difracction mineralogy (Izquierdo, 1993). The study reports plagioclase as well as cristobalite and kaolinite. Plagioclase is of primary origin, whereas the kaolinite and cristobalite were formed in a vadose zone due to condensation of steam.

Geothermal steam is invariably accompanied by a small portion of CO_2 and H_2S; the latter readily oxidizes, usually near the surface, to H_2SO_4 producing a strong acid that immediately attacks the surrounding rocks (Browne, 1990). Volcanic rocks, *e.g.* pumice and glass, are readily dissolved in a distinct fashion, producing the usual acid indicating assemblage of residual silica (but not sinter) with other minerals such as kaolinite, alunite, hematite, jarosite and pyrite.

However, the case herein reported only included kaolinite and cristobalite, as mentioned. This, in addition to the very

Table 1. Stages of the eruptive history of El Ceboruco.

STAGE	CHARACTERISTICS	CLASSIFICATION & MINERALOGY
1	■ Formation of main cone. Lava flows 1-5 m thick, *aa* type.	Andesites (Pl + Cpx + Ol + Tmt) (40 km^3).
	■ Outer caldera & dykes. Peripherical flows & scoria cones.	Similar andesites plus high alumina basalts.
	■ Forming of C. Pochotero dome, C. Pedregoso & Destiladero flow.	Rhyolites & rhyodacites.
	■ Jala pumices & Marquesado ashes, 1000 years ago.	Rhyolitic & rhyodacitic (2 km^3).
2	■ Dos Equis dacitic dome into the outer caldera.	Dacites (Pl + Opx + Cpx + Il + Tmt) (1.3 km^3)
	■ Inner caldera in the Dos Equis dome.	
	■ Copales dacitic flow.	Dacites (+ glass + xenolites) (1.4 km^3)
3	■ Andesitic dome at outer caldera.	Andesites (Pl + Cpx + Ol + Tmt).
	■ Andesitic *aa* type lavas. North of volcano.	Andesites (Pl + Cpx + Ol + Tmt).
	■ El Ceboruco flow (spongy andesites).	Andesites.
	■ Historic eruption (1870). Flow 7.5 km long & 200 m thick.	Dacites (Pl + Opx + Cpx + G + Il + Tmt) (1.3 km^3)

NOTES: Pl = Plagiociase, Opx = Orthoprioxene, Cpx = Clinopioxene, G = Glass, Il = Ilmenite, Ol = Olivine, Tmt = Tianiferous magnetile.

restricted extension of the altered zone, leads us to think that the mass flow discharging of the probable deep reservoir is very low. This could reduce the geothermal potential of the zone, as it seems to be suggested by the results of the exploratory well.

Exploratory Drilling

The first deep exploratory well, named CB-1, is located approximately on the southwestern slope of the El Ceboruco Volcano, about 5 km away from its summit. Drilling of the CB-1 was preceded by a shallow (400 meters depth) gradient well, results of which are yet published (Viggiano, 1993). Both wells were drilled at the same site.

Well CB-1 reached 2,800 meters depth, but here are reported only first 2,240 meters, which is the depth with available results up to date. Every 10 meters cuttings were studied, as well as four from the five core samples, by using a petrographic microscope.

It is well known that there are always problems working with cuttings, particularly in this well where a mixture of air with mud (aerated fluid) was used as a drilling fluid; hence, this produced very small cuttings indeed. Nevertheless, a good view of rock textures and mineralogy was experienced.

Lithology

Figure 2 illustrates the primary petrology of the subsurface rocks cut by the well. Most of those rocks belong to the calcalkaline suite and are predominantly basalts, basaltic andesites and subordinate rhyolites, with different textural and mineralogical varieties. However, at least two horizons of volcanic aglomerates were found (Figure 2).

Noting of the lithogical sequence in that figure can be related to the SMO volcanics, as were expected prior to drilling. An ignimbritic rock was identified in the interval between 1,540 and 1,650 meters (Figure 2). Below this interval, cuttings included many fragments of ignimbrites, but predominately basalts and basaltic andesites. This led to the conclusion that numerous amounts of ignimbritic horizons had been intersected, and, therefore, the SMO series had been found. However, that abundance of ignimbritic chips seems to be a result of mixing of rocks that fell down during drilling, given the nature of the drilling fluid, instead of the presence of the SMO volcanics.

As for the ages of subsurface rocks penetrated by the well, some ideas are given in Figure 2, but without dating support.

Hydrothermal Mineralogy

Figure 3 shows the hydrothermal alteration interpreted from petrographic analysis. A striking feature for rocks from a geothermal well, is how few rocks have been intensively altered: most chips show only scarse alteration. Generally, the process of low intensity alteration is also reflected by the relative stability of primary minerals, for instance, the unaltered ferromagnesians.

In general, there are two different alteration regimes. One of them is localized from 420 to 650 meters depth, and is characterized by the illita + montmorillonite + quartz + epidote + calcite + pyrite + zeolites (probably laumontite and/or heulandite) assemblage. The other is localized from around 800 meters depth to the bottom, and is relatively unhomogeneous; is characterized by almost the same minerals but in lesser abundance than those of the first zone, with no epidote, nor illite, much less pyrite and much more chlorite (specially penninite) (Figure 3).

The deeper alteration zone is characterized also by the lack of veining, contrasting with the shallower one; this lack of cavities filling process probably indicates that there was a very low permeability at the moment of mineral deposition.

An immediate conclusion from such an alteration mineralogy, is that no important geothermal system has been active in the lower half of the well. The shallower interval 420 to 650 meters depth, however, presents a hydrothermal mineralogy typical of geothermal systems, whose temperatures were probably in excess of 230°C.

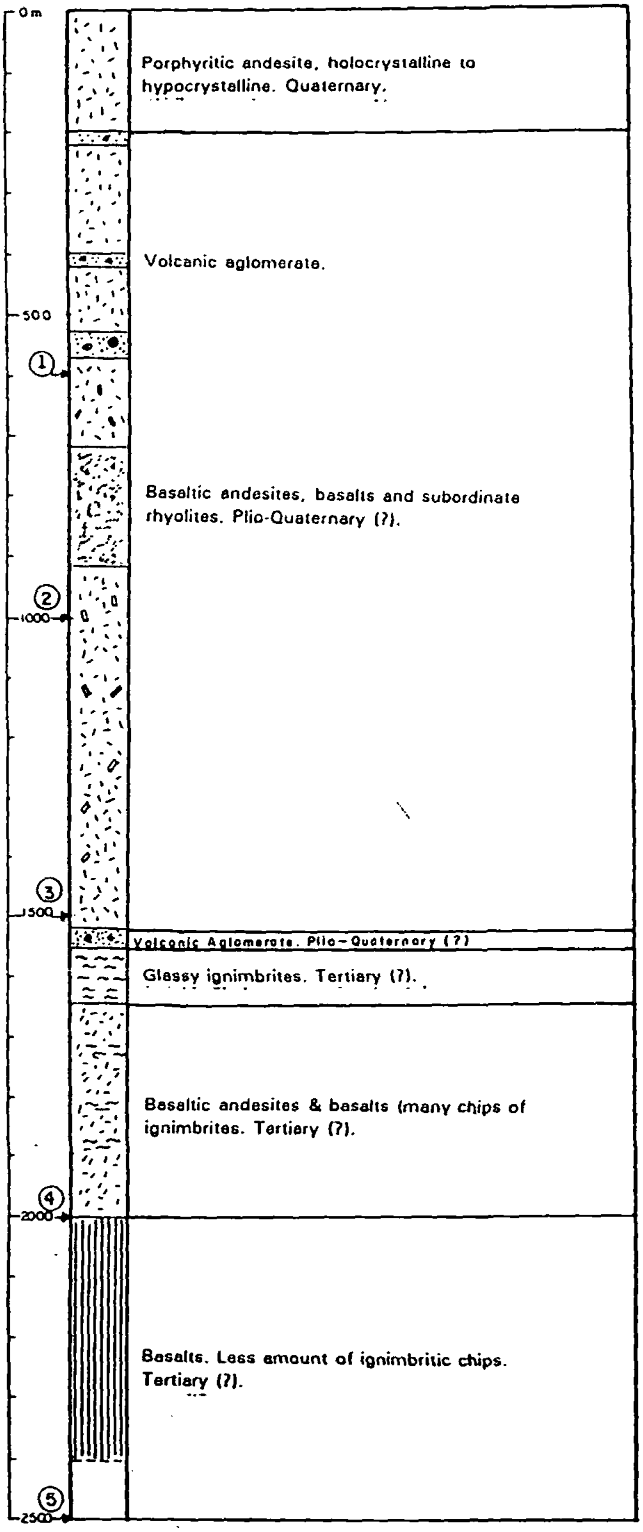


Figure 2. Simplified lithology of well CB-1. Core samples are indicated with arrows and numbers 1 to 4.

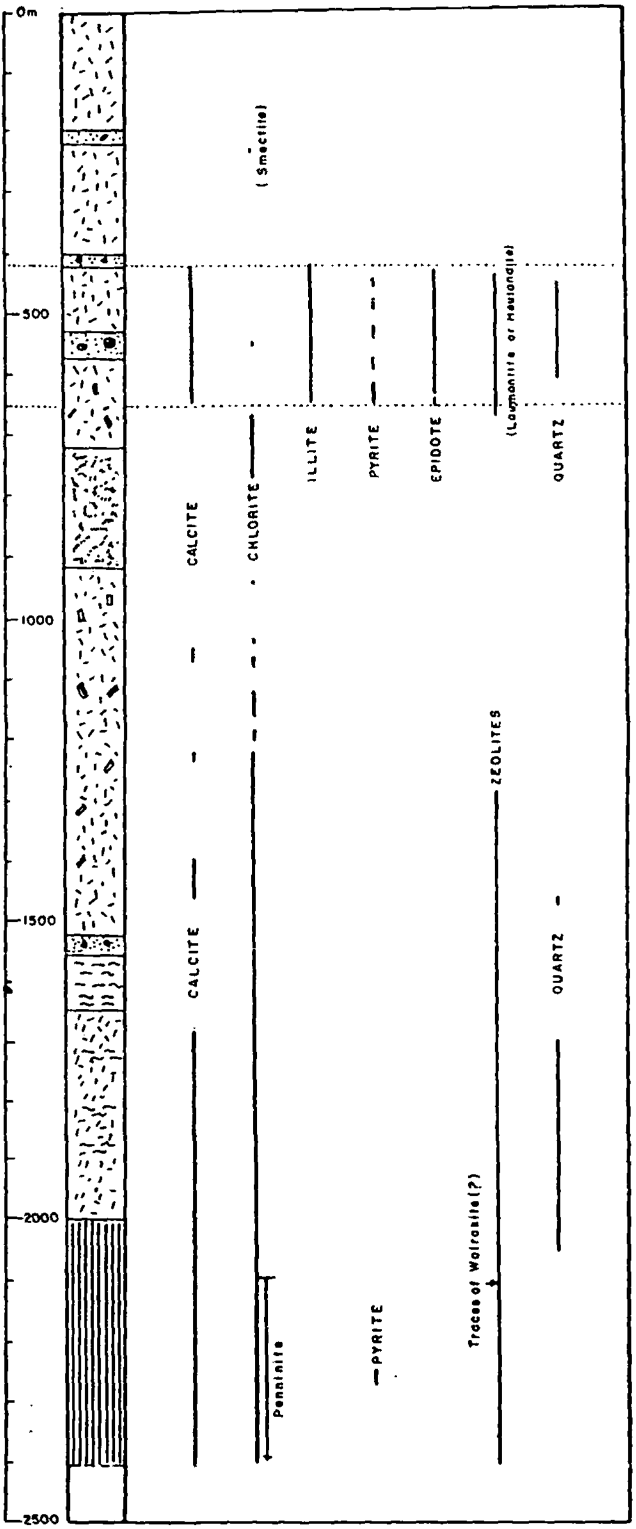


Figure 3. Hydrothermal mineralogy of well CB-1. High alteration interval is marked with dots.

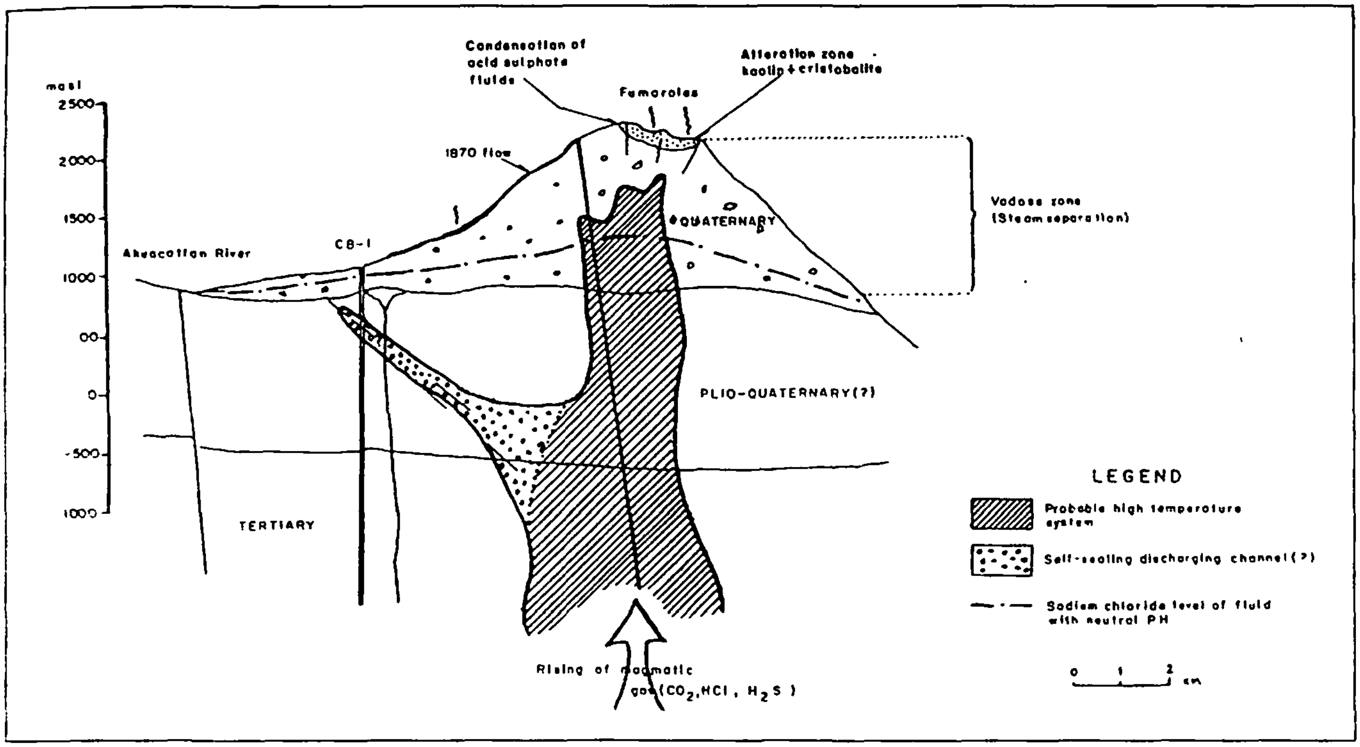


Figure 4. Preliminary flow model for El Ceboruco.

It is appropriate to mention that the present, maximum measured temperature in the well was around 112°C.

Flow Model for El Ceboruco

After a previous model of the El Ceboruco Volcano (Viggiano, 1993), and taking into account the mentioned results of well CB-1, it is possible that this zone would be a high relief system, which flashes steam above the sodium chloride water table. Its remaining temperature would serve as a heat source, which is capable to heat an aquifer forming an apparently restricted geothermal system (Figure 4).

Geothermal fluids from such a system upflow through recent lava conduits, faults and fractures, and form in time, a steam or vadose zone with variable amounts of H_2S and CO_2 discharging as fumaroles onto the surface. The H_2S oxidizes giving a corrosive acid that attacks the rocks to produce cristobalite and kaolinite among others. Superficial discharge was very limited, as far as it can be judged after the surface alteration. Deep lateral extension of the system is unknown, but probably was partially extended through the future site of well CB-1 as a narrow, shallow discharge zone (Figure 4).

That discharge has ceased today, but could explain the mineral alteration zone found in the CB-1 between 420 and 650 meters depth. The hydrothermal mineral assemblage, headed by epidote, represents past temperatures over 230°C, as mentioned above. Upflow could happen through a fault zone with no superficial evidence, and would then be thoroughly self-sealed and cold.

The rest of the alteration represents a regional low temperature (<150°C) aquifer, according to the mineral characterized by heulandite (?), which is presently quite impervious. Notice, however, that these alteration processes took place below the sodium chloride water table (Figure 4).

Outstanding Remarks

- In spite of unsuccessful geothermal results of the first deep exploratory well in the El Ceboruco Volcano, its volcanological and structural features allow us to assume the presence of an active, high temperature geothermal system beneath it. This probable system seems to be more restricted than anticipated to the central volcanic conduit, as has been indicated by well CB-1, but could be large enough in dimensions to be used in a small geothermal development. That restriction must be taken into account however, if a second exploratory well is drilled near the volcano.
- Previous geological and structural interpretations on the regional framework of the El Ceboruco Volcano must be reviewed, according to the lithology found in the well. It is very important to understand the SMO volcanics, which outcrops 8 km away from the well.
- Standard geophysical techniques used in decision making to locate additional exploratory wells, must be carefully

considered. Especifically, the well CB-1, which was located among others, on the basis of an apparently important resistivity anomaly after a magnetotelluric survey, but, was not a cold nor hot water, nor an alteration zone, at depth, which could be associated to that anomaly.

References

Browne, P.R.L., (1990). Hydrothermal alteration and geothermal systems. University of Auckland, New Zealand, Publication, p. 86-102.

Izquierdo, G., (1993). Letter communication.

Luhr, J.F., S.A. Nelson, J.F. Allan and I.S.E. Carmichael, (1985). Active rifting in Southeastern Mexico: Manifestation of an incipient eastward spreading ridge jump. *Geology*, v. 13, p. 54-57.

Nelson, S.A., (1986). Geología del Volcán Ceboruco, Nay., con una estimación de riesgos de erupciones futuras. UNAM, Revista del Instituto de Geología, v. 6-2.

Romero R., F., y S.H. Palma G., (1993). Propuesta para la localización del pozo CB-1. CFE, Residencia ElCeboruco, Informe 03/93. Unpublished.

Stock, J.M., (1993). Tectónica de placas y la evolución del Bloque Jalisco, México. GEOS, Bol. de la Unin Geofísica Mexicana, v. 13-3.

Viggiano G., J.C., (1993). Modelo conceptual aproximado del yacimiento geotérmico en el Volcán Ceboruco.Geotermia, 9-3.

DEPARTAMENTO DE EXPLORACION
OFICINA DE GEOFISICA

CARACTERISTICAS GENERALES DEL LEVANTAMIENTO GRAVIMETRICO DE LAS ZONAS DEL DOMO SAN PEDRO Y VOLCAN CEBORUCO, NAYARIT.

GENERALIDADES

En el levantamiento gravimétrico en la zona geotérmica del Volcán Ceboruco y Domo de San Pedro en el Estado de Nayarit, las estaciones se ubicaron aprovechando los caminos de terracería y transitables a pie existentes en la zona de estudio, localizados en las cartas topográficas escala 1:50,000 editadas por el INEGI, con la finalidad de posicionarlas en éstos, apoyándose con fotografías aéreas de la zona.

La separación entre estaciones fue en average promedio de 1 kilometro, reduced disminuyendo cuando se considero pertinente detallar aspectos estructurales. La elevación se obtuvo considerando la correspondiente a su ubicación en las cartas topográficas, es decir que ésta pudiera variar +/- 10 metros ya que la configuración de curvas de nivel en las cartas es de cada 20 metros. elev ± 10m

El equipo utilizado fue un gravímetro Worden Master modelo 111, con una constante de 0.0933 miligales. La ubicación en el terreno se efectuó mediante el odómetro del vehículo, el cual marca distancias a cada 100 metros, es decir, se considero que se podrían tener errores del orden de +/- 25 metros.

De antemano se tiene conocimiento, de los errores a que puede dar lugar el haber ubicado las estaciones y obtenido la elevación correspondiente de la manera en que fue referido en los párrafos anteriores; así, considerando que por cada metro se tenga una variación vertical de 2 u.g., al tener un error de +/- 10 metros en la cota de elevación de las estaciones, daría lugar a diferencias de +/- 20 u.g. Por lo anterior la determinación de la distribución de "cuerpos fuente" y "basamento" en el modelado gravimétrico habrán de considerarse con las reservas del caso.

Para la zona se tienen estudios gravimétricos de carácter regional efectuados por PEMEX , considerándose que presentan un comportamiento similar en la información de Anomalía Bouguer.

El valor absoluto de la gravedad observada fue llevado a la zona de estudio, a partir de una base gravimétrica ubicada por PEMEX en el Aeropuerto de Guadalajara, cuyo valor es de 978,2075.6 u.g..

Lo anterior, se realizó obteniendo las diferencias entre estaciones gravimétricas ubicadas sobre la Carretera Federal No. 15, Guadalajara-Tepic a cada 10 Km. y efectuando loops máximos de 2 horas y cuya deriva no fuera mayor de 1.5 u.g. y divergencia de 1.0 u.g. hasta llegar al crucero de Tetitlán con la carretera mencionada llegando con un valor de gravedad de 978,4420.8 u.g. correspondiente a la estación G-11.

OBJETIVO

Definir el patrón estructural y distribución del "basamento" (gravimétrico) de la zona de estudio y su relación con el sistema hidrotermal.

ETAPA DE CAMPO Y CALCULO DE LA ANOMALIA BOUGUER

La observación gravimétrica se efectuó mediante loops con una duración máxima de 2 horas, observando doble vez las estaciones base y "cerrando" polígonos regionales con tolerancias máximas de 1 u.g. y a detalle 1.5 u.g.. Posteriormente se efectuó el cálculo de Anomalía de Bouguer aplicando la corrección por elevación y de Bouguer, considerándose una densidad de corrección de 2.4 gr/cm^3 valor que ha sido utilizado por PEMEX en esta región, así mismo la Anomalía de Bouguer fue referida al nivel del mar, aplicando la corrección topográfica a cada estación.

PROCESAMIENTO DE LA INFORMACION

A la Anomalía de Bouguer se le aplicaron procesos matemáticos que consistieron en filtrados, tanto en el dominio espacial como en el de las frecuencias, para obtener los diferentes efectos regionales-residual y posteriormente analizar la correlación de los lineamientos definidos en la información gravimétrica, con los rasgos geológico estructurales que prevalecen en la zona de estudio.

INTERPRETACION

Al analizar la Anomalía de Bouguer (plano anexo), se observa como el gradiente disminuye de occidente a oriente, presentándose los valores más altos (-800 u.g.) en la Zona de Zapotán y Sierra el Guamuchil y los más bajos en el Volcán Ceboruco (-1200 u.g.), además de que se definen 5 lineamientos NW-SE principalmente y únicamente dos NE-SW, marcados con sus ejes de Máximos y mínimos gravimétricos respectivamente.

La relación geológica que presenta dicha información y que sobresale en el plano de Bouguer es el máximo que se presenta en las zonas de Zapotán y Sierra El Guamuchil, asociándose al comportamiento del granito, considerándose éste como basamento de la secuencia volcánica, de la Sierra Madre Occidental (S.M.O.) y Faja Neovolcánica por el comportamiento de la información es posible predecir que se va profundizando hacia la parte central del área de estudio y hundiéndose aun más en la zona del volcán El Ceboruco.

Los mínimos gravimétricos presentes en Amado Nervo, Tetitlán, Ahuacatlán, Domo San Pedro y noroeste de Chapalilla, por sus dimensiones, mas bien están asociados a efectos locales y más someros, es decir a eventos que se llevaron a cabo durante la formación de la Faja Neovolcánica, de la misma manera el máximo presente en la zona de Loma Atravesada y Cerro las Cuevas.

La interpretación cuantitativa, a la fecha a considerado, modelado bidimensional, utilizando el algoritmo de Talwani, ésta se inicio tomando en cuenta la geología superficial y la interpretación cuantitativa de sondeos eléctricos verticales, para poder tener una idea del efecto gravitacional causado por la secuencia volcánica de la Sierra Madre Occidental y Faja Neovolcánica y tratar de definir la cima del basamento granítico que aflora al occidente del área de estudio.

Mediante ensayo y error se modeló inicialmente sobre la Anomalía de Bouguer considerando un sólo cuerpo que fuera equivalente a la secuencia volcánica mencionada con una densidad de 2.4 gr/cm3 y cuya base fuera representativa de la topografía del granito.

Al interpretar una serie de perfiles bajo dichas consideraciones, se determinó que se trata de una depresión delimitada al occidente por la Sierra de Zapotán y al oriente por la Sierra Madre Occidental, es decir el basamento granítico que aflora en la zona de Zapotán, se encuentra hundido, entre ambas sierras presentando en la parte central levantamientos tipo horts, provocados por el ascenso de magma que ha dado lugar a aparatos volcánicos durante la formación de la Faja Neovolcánica, tal es el caso de los cerros El Fraile, Loma Atravesada, Las Bartolinas, Lobos, Los Ocotes y la Mesa de Santa Isabel.

Las depresiones interpretadas en las zonas de Amado Nervo, Domo San pedro, Uzeta, Tetitlán y Ceboruco, les corresponden profundidades que van de 1 a 1.3 Km. de profundidad de acuerdo al modelado inicial.

Por lo menos en la zona del Ceboruco, específicamente en el sitio del pozo CB-1, las densidades determinadas en los núcleos obligan a modificar las consideraciones iniciales, ya que el pozo a la profundidad de 2800 metros no reportó rocas graníticas, quedando sólo en la cima de la secuencia volcánica denominada Sierra Madre Occidental.

Posteriormente se efectuó una reinterpretación del perfil gravimétrico con dirección Este-Oeste, específicamente en la zona del pozo exploratorio CB-1, lográndose una buena aproximación entre el valor calculado y el observado mediante ensayo y error, la interpretación presenta un comportamiento estructural similar al modelo inicial, con la diferencia de que las profundidades para las depresiones detectadas son del orden de cinco kilómetros de profundidad.

CONCLUSIONES

Mediante el análisis de la interpretación cuantitativa se logró definir que la zona en estudio, se encuentra inmersa en una cuenca, la cual de acuerdo con las hipótesis geológicas, el basamento granítico y la secuencia de la Sierra Madre Occidental se han hundido, en la parte central a consecuencia de una tectónica extensional, siendo la parte mas profunda en donde se ubica el Volcán Ceboruco.

El desplazamiento del gradiente gravimétrico hacia el noreste en la zona del Cuastecomate y Río Tetiteco, obedece a un desplazamiento lateral en ésta dirección de la Sierra de Zapotán para continuar hacia el Sureste con el nombre de la Sierra el Guamuchil, por lo que el cause del río mencionado actúe como límite estructural en ésta dirección.

En la parte norte, en las zonas de Milpillas y San Pedro Lagunillas el fenómeno descrito anteriormente es similar y nuevamente con desplazamiento hacia la parte central.

Hacia la porción oriental, en la zona de Tequepexpan y El Cajón existe un ligero gradiente allanándose NW-SE, para después cambiar de dirección en la zona del Volcán El Ceboruco a NE-SW, concordantemente al lineamiento estructural del Río Tetiteco.

Por lo antes expuesto la zona en estudio del Volcán el Ceboruco y Domo San de San Pedro se encuentran a nivel basamento granítico en un bloque hundido, delimitado en su parte occidental y oriental por la Sierra de Zapotán y Sierra Madre Occidental, al sur por el desplazamiento lateral que sufre la de Zapotán con la de Guamuchil y al norte por el lineamiento NE-SW de Milpillas San Pedro Lagunillas.

Al llevarse a cabo el desplazamiento vertical del basamento hacia la parte central, éste seguramente dio lugar a zonas de debilidad por donde ha ascendido el vulcanismo reciente durante la formación de la Faja Neovolcánica, presente en la zona y a su vez provocó algunos hundimientos locales en el mismo para dar lugar a las depresiones detectadas en las zonas de Amado Nervo, San Pedro y Ceboruco, siendo la más profunda la última, debido a los colapsos sufridos durante la expulsión del magma del Ceboruco en sus últimas actividades.

Morelia, Mich., a 27 de abril de 1994.

Asunto: Comentarios al reporte 5/94
de la Residencia El Ceboruco

Ing. J. Francisco Arellano Guadarrama
Jefe de la Oficina de Geofísica
PRESENTE

En relación con el reporte 5/94 de la Residencia El Ceboruco escrito por O. Palma y que me fue proporcionado para su lectura y comentarios el día 20 del presente, hago notar los siguientes aspectos que aclaran las preguntas planteadas por usted respecto a:

- Elección del regional
- Densidades reportadas
- Como involucrar las densidades reales en el modelado
- Omisión de las altas frecuencias del regional en el modelado
- Razones para el uso del regional suavizado

Se presenta una síntesis de los comentarios verbales hechos el día el día 22 del presente.

Las densidades citadas son correctas, los valores medidos en la Oficina de Geofísica para núcleos del pozo CB-1 son los siguientes:

ROCA	PROFUNDIDAD EN M	DENSIDAD EN G/CM^3
Basalto	600 - 604	2.86
Andesita	1000	2.76
Conglomerado andesítico	1500	2.05
Andesita vesiculada con relleno de cuarzo	2000	2.69
Andesita	2000	2.73

La identificación litológica fue hecha por el suscrito y no corresponde a la clasificación oficial.

Las densidades utilizadas en el modelado tienen valores negativos, -2.7 g/cm^3 para el relleno volcano-sedimentario y -2.6 g/cm^3 para el basamento. Esto significa que en realidad se está trabajando con contrastes de densidad y que el relleno se está considerando como un cuerpo menos denso, modelado con un menor, aunque esta disminucion tiende a compensarse en rocas saturadas debido a su mayor porosidad efectiva.

Se incluye el peso (masa) de las rocas húmedas, con objeto de que se tenga una idea de la porosidad efectiva de las muestras mas compactas.

El cambio de peso corresponde al agua absorbida por lo que se puede estimar la porosidad de la roca a partir de la densidad del agua.

Como puede notarse en la muestra 3, que es prácticamente impermeable, alrededor de unos 1-2 g son debidos al humedecimiento exterior de la roca.

La muestra 2 se deshizo durante el proceso de saturación. La muestra 4, afin a la 2, tiene un valor tentativo pues la muestra es excesivamente deleznable y se pierden fragmentos de la masa durante su manipulación

MUESTRA	MASA g SATURADA	MASA g HUMEDA	VOLUMEN CM^3	DENSIDAD SATURADA g/cm^3	DENSIDAD HUMEDA g/cm^3	LITOLOGIA
1 a)	494.7	487.0	190	2.6	2.6	Andesita
b)	199.7	181.5	80	2.5	2.3	afanitica
2	-	-	-	-	-	intrusivo intemperizado
3 a)	476.2	474.2	180	2.6	2.6	intrusivo
b)	164.2	163.9	60	2.7	2.7	sano
4	528.1	-	230	2.3	-	intrusivo intemperizado
5 a)	402.9	397.5	160	2.5	2.5	Intrusivo Pian de B ? Intemperizada
b)	352.7	-	130	2.7	-	Sano con xenolito máfico
6	34.6	32.6	15	2.3	2.2	Xenolíto intrusivo alterado.
7	198.4	197.2	80	2.5	2.5	Andesitas afaniticas
8	730.5	723.4	300	2.4	2.4	Toba riolitica.

MUESTRA	MASA g SATURADA	MASA g HUMEDA	VOLUMEN CM^3	DENSIDAD SATURADA g/cm^3	DENSIDAD HUMEDA g/cm^3	LITOLOGIA
9	261.0	260.0	100	2.6	2.6	Caliza masiva
10 a)	465.5	464.8	190	2.5	2.4	Areniscas completas
b)	198.0	196.9	80	2.5	2.5	
11 a)	397.0	-	180	2.2	-	Toba riolítica
b)	269.7	-	115	2.3	-	
12 a)	495.0	485.8	210	2.4	2.3	Riolita cocoran
b)	456.0	451.3	190	2.4	2.4	
13	155.2	150.5	70	2.2	2.2	Riolita fluidal
14	329.7	324.0	150	2.2	2.2	Riolita toba
15	529.1	520.7	230	2.3	2.3	Riolita fluidal
16 a)	266.2	-	120	2.2	-	Riolita sana
b)	535.3	-	240	2.2	-	
17	563.5	-	260	2.2	-	Ignimbrita
18	343.1	330.9	140	2.5	2.4	Ignimbrita

Se subrayaron los valores recomendados para modelado.

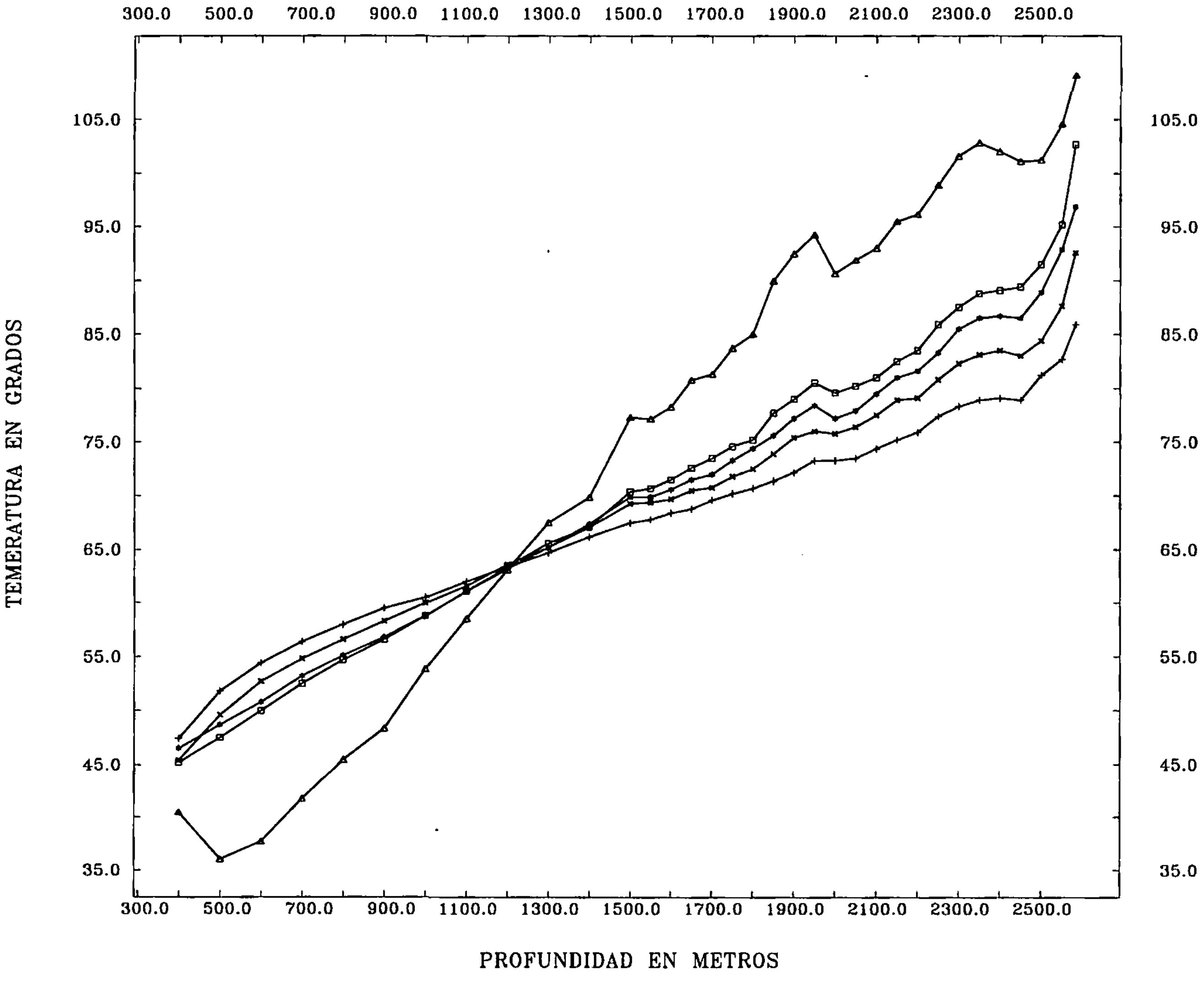
Las rocas que no exhiben variaciones de densidad entre la muestra húmeda y la saturada tienen una porosidad pequeña, para fines gravimétricos.

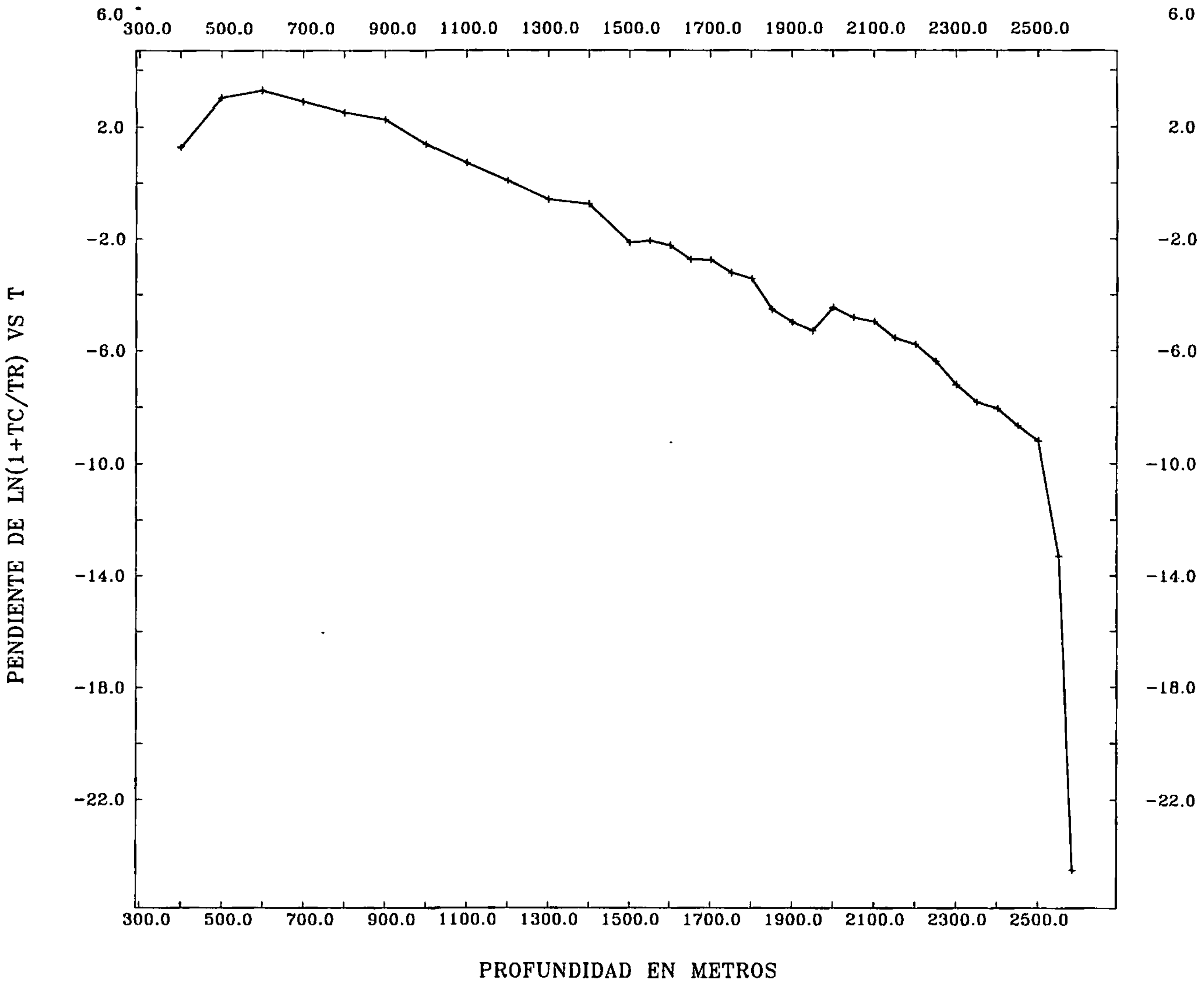
La precisión de las estimaciones puede mejorarse pero se considera que los datos ofrecidos son suficientemente útiles y las mejoras pueden postergarse para futuras medidas de densidad.

Los valores son sólo indicativos, pues debe recordarse que para el modelado se trabaja con contrastes de densidad y éstos se refieren a un valor "medio" que depende de la forma de hacer la separación regional-residual, lo que inutiliza la ventaja de hacer medidas muy precisas.

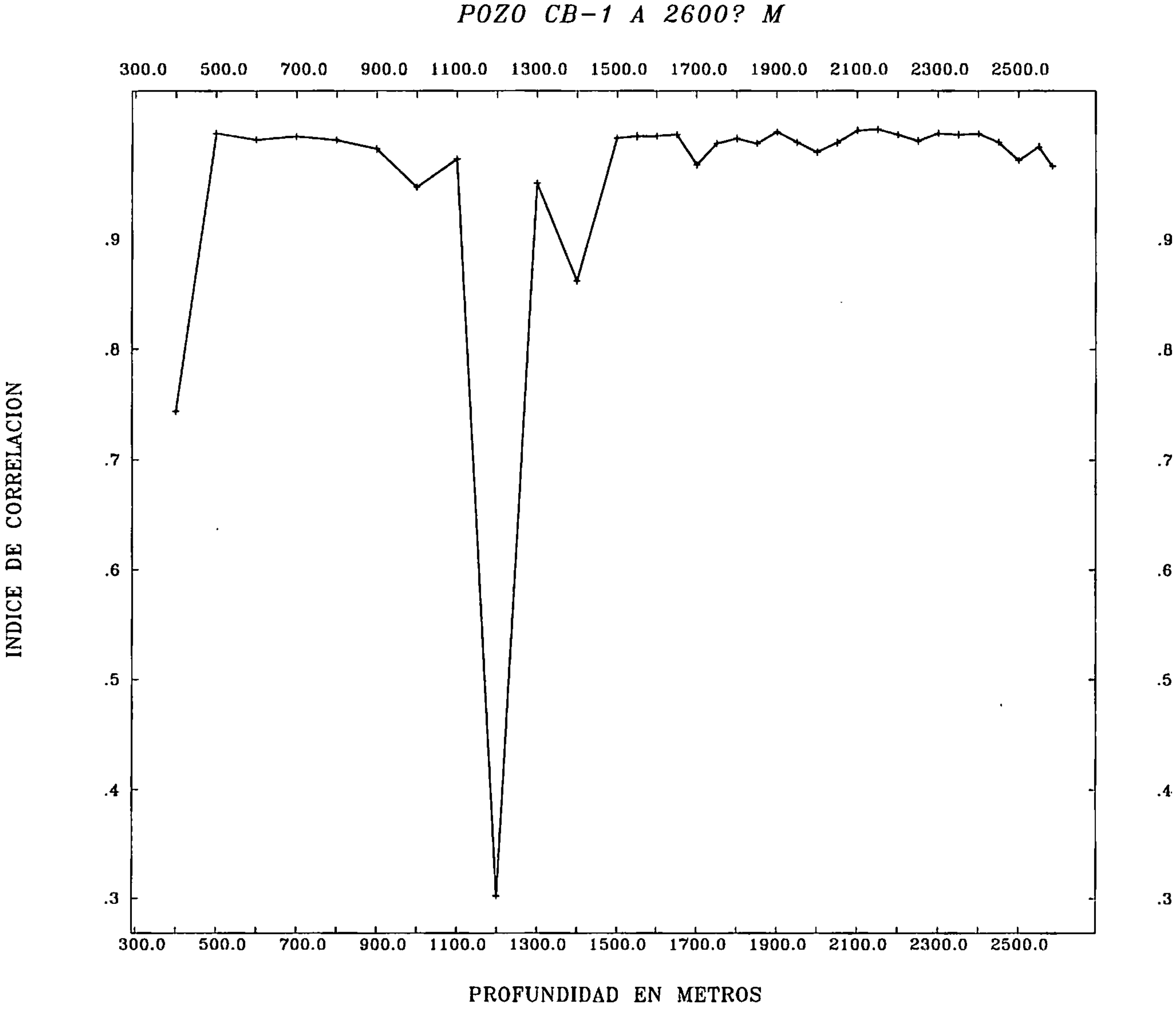
Junio-1992.

POZO CB-1 A 2600? M



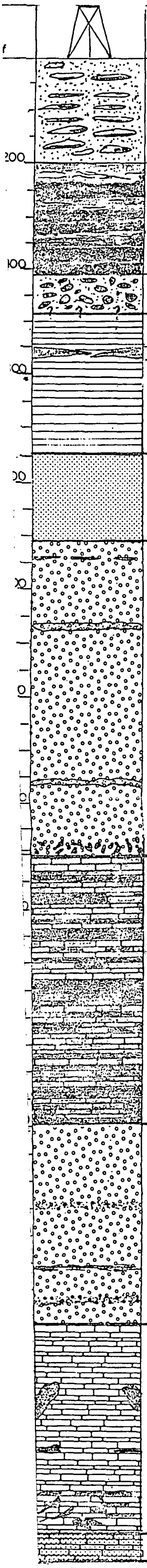


POZO CB-1 A 2600? M


POZO CB-1 A 2600? M
300.0
500.0
700.0
900.0
1100.0
1300.0
1500.0
1700.0
1900.0
2100.0
2300.0
2500.0
INDICE DE CORRELACION
.9
.8
.7
.6
.5
.4
.3
PROFUNDIDAD EN METROS

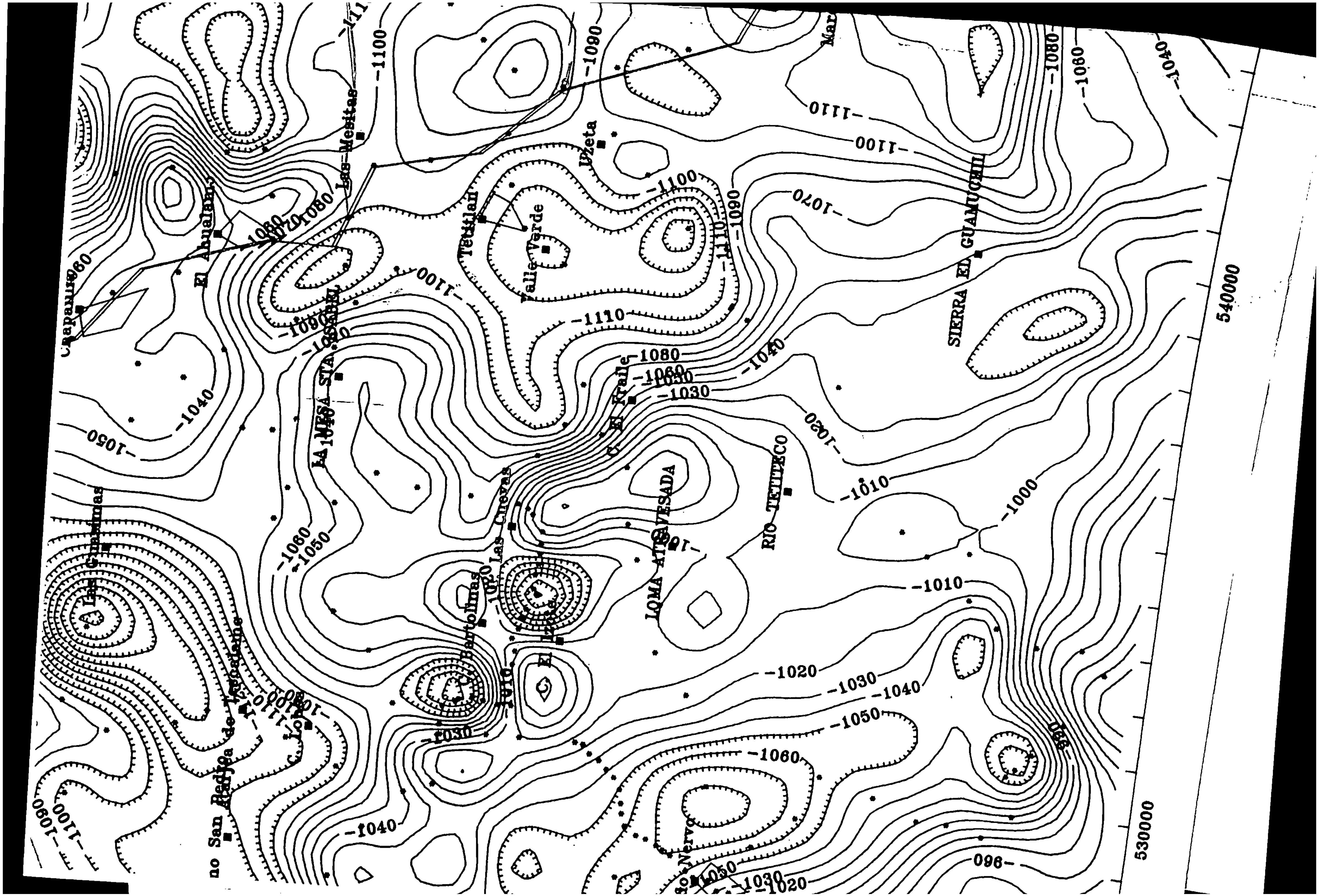
COLUMNA LITOLOGICA · POZO PROFUNDO PCB I

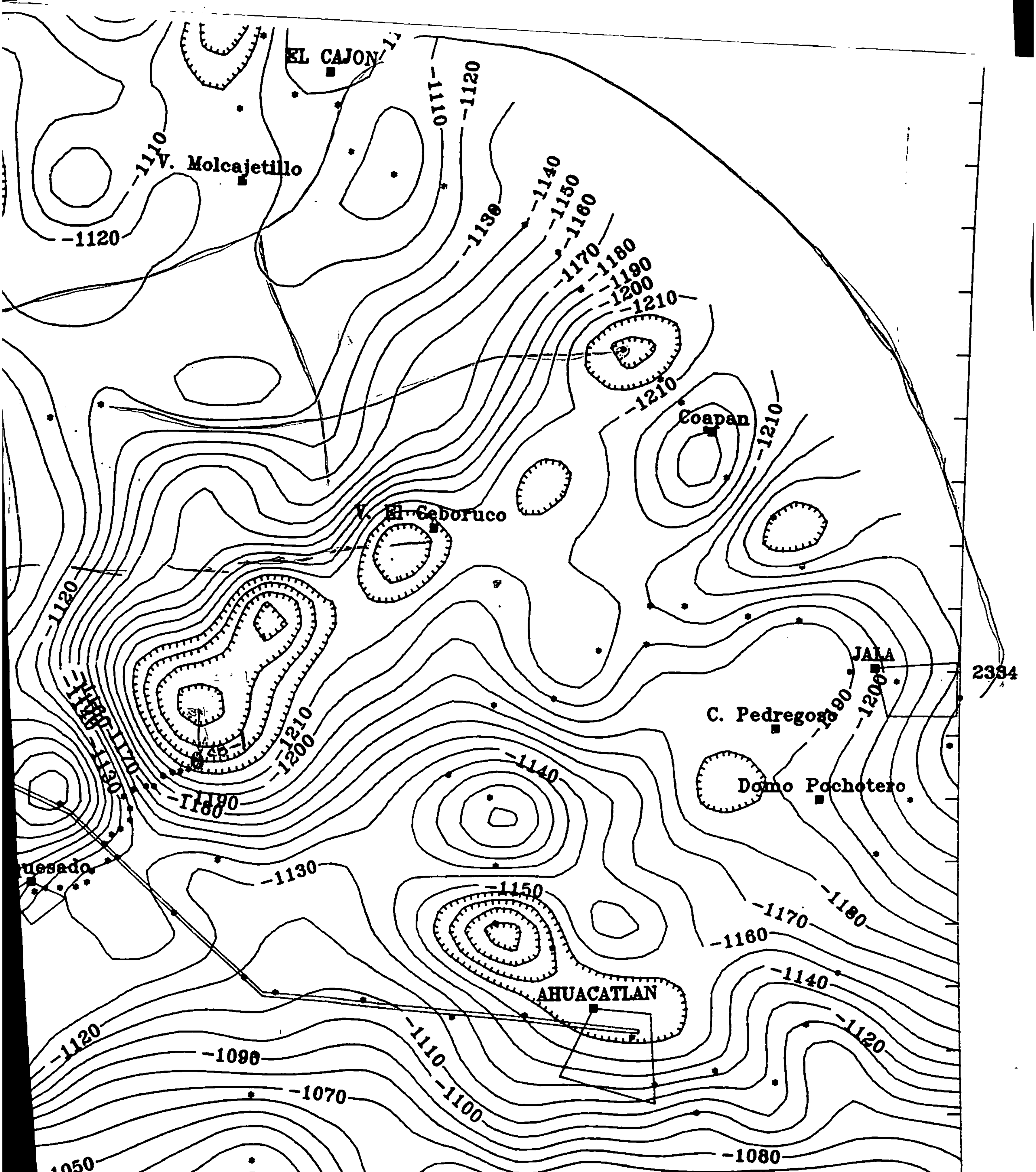
(PRELIMINAR)



CLASIFICACION MEGASCOPICA	CLASIFICACION PETROGRAFICA	TEXTURA y MINERALOGIA	POSICION ESTRATIGRAFICA
Cenizas en alternancia con coladas andesiticas, del Volcan "Ceboruco"	Andesitas de augita	Portidica, holocristalina Plagioclasas	Formacion "Ceboruco"
Alternancia de riolitas vitreas, tobas, dacitas andesitas, andesitas - basalticas y basaltos vesiculares. (Nucleo continuo)	Riolitas vitrea Andesitas basalticas y basaltos	Porfiritica, holocristalina vitrea, intergranular plagioclasas, ferromagnesianos, olivino	FAJA VOLCANICA MEXICANA
Conglomerado heterogeneo	Conglomerado polimictico	Cantos rodados riolilicos andesiticos y basalticos	
Andesita-basaltica magnetica	Andesitas-basalticas y basaltos	Porfiritica holocristalina Plagioclasas olivino	
Conglomerado heterogeneo	Riolita esferulitica	F. Q. vitrea	
Andesita basaltica magnetica	Andesita basaltica y basaltos de olivino	• Alteracion deuterica Porfidica holocristalina Plagioclasas augita magnetita olivino	
Andesita amagnetica (dacita)	Andesita Afieltrada	Afirica afieltrada	
Horizonte ignimbritico Horizonte brecha Andesita-basaltica con facies vesiculares parcialmente rellenas de zeolitas (chabazita) Horizonte brecha Aglomerado andesitico	Andesitas basalticas con intercalaciones de andesita afieltrada Conglomerado andesitico	Intergranular porfiritico, afieltrada Plagioclasas, magnetita oxidos olivino zeolitas calcita de remplazamiento	
Alternancia de tobas pumicitas, riolitas, vitreas Ignimbritas, y andesitas basalticas magneticas	[illegible] Ignimbritas liticas vitreas (ash flow) intercalados con andesitas basalticos y basaltos	vitrea piroclastica Holocristalina porfiritica plagioclasas feldespatos cuarzo arcillas zeolitas	
Horizonte brecha Basalto vesicular con zeolitas (magnetico) Horizonte riolita Horizonte brecha	Basalto	Porfiritico vesicular holocristalino y merocristalino plagioclasas, olivino zeolitas clorita, magnetita • alteracion deuterica	
Ignimbrita riolita fluidal con oxidacion	Emplazamiento domo Ignimbrita vitrea riolita alterada	vitrea, fluidal, porfiritica feldespatos plagioclasas cuarzo, arcillas, oxidos mica y calcita de remplazamiento como de relleno de fracturas	Formacion SIERRA MADRE OCCIDENTAL Oligoceno - Mioceno ?
Dacita andesita [illegible]		Porfiritica merocristalino plagioclasas cuarzo	

fig 2


Las Mesitas
El Abualam
Tetitlan
Valle Verde
Zeta
SIERRA ED GUAMUCHIL
LA MESA STA
C. El Fraile
LOMA ATRAVESADA
RIO TETITECO
Las Cuevas
Bartolomas
El Izote
Las Guasimas
San Pedro de
Lobo
Nervo
Mar
540000
530000
-1100
-1090
-1080
-1110
-1070
-1060
-1050
-1040
-1030
-1020
-1010
-1000
-990
-960


EL CAJON
V. Molcajetillo
V. El Ceboruco
Coapan
JALA
C. Pedregoso
Domo Pochotero
AHUACATLAN
uesado
-1110
-1120
-1130
-1140
-1150
-1160
-1170
-1180
-1190
-1200
-1210
-1090
-1100
-1080
-1070
-1060
-1050
-1040
-1030
-1020
2334
2324
550000

GEOPHYSICAL STUDIES CEBORUCO GEOTHERMAL RECONNAISSANCE AREA

Phillip E. Wannamaker, UURI J. F. Arellano G., CFE
Howard P. Ross, UURI

Background

- Ceboruco area, western Neovolcanic Belt, identified by CFE as a promising geothermal area from geologic,geochemical, geophysical studies
- Extensive geophysical program, 1983-1992; ending with 90 MT stations
- CB-1 drilled to 2,800 m; T max. = 112 C

Program for 1994

- Review and critique MT data and interpretation (UURI)
- Complete new MT modeling/interpretation, as needed (UURI and CFE)
- Review supporting geologic and geophysical data (UURI)
- Review Ceboruco exploration strategy (UURI)

CEBORUCO - GEOPHYSICAL STUDIES

Data Reviewed

- Regional Geology, Tepic-Zacoalco Graben, Nayarit
- El Ceboruco Geothermal Project, State of Exploration
- Gravity Studies, and Bouguer Anomaly Map
- Regional Aeromagnetic Studies
- Integration of Electrical Resistivity Studies
- Magnetotelluric Data, and Interpretations
- CB-1: Lithologic Column and Temperature Results

Problems Encountered

- Schedules - P. Wannamaker, H. Ross, GRC
- Report review - Spanish to English
- Correspondence and discussion
- GEOTOOLS
- Location of CB-1 uncertain to UURI
- GeoEvaluaciones MT Plates 1-14 not available
- GeoEvaluaciones MT Plot Ceboruco-s24 missing

GEOPHYSICAL SUMMARY

AEROMAGNETICS

- Regional data, 6,000 sq km
- Extensive processing, analytical operations
- Interpretation confirms NW-SE, NE-SW trends proposed by photogeologic interpretation
- Zones of low magnetization correspond to hydrothermal alteration
- 2-D Model of magnetic basement at 800 - 1200 m
- Indicates a zone of granitic basement

REGIONAL GRAVITY STUDIES

- 450 sq km; 120 stations at 1 km spacing
- To assist in structural interpretation and morphology of "basement"
- Includes zones of interest from electrical resistivity (VES) and magnetotelluric (MT) data
- Bouguer Gravity Anomaly map defines 5 NW-SE lineaments, and 2 NE-SW trends
- Several gravity minima, including: Amado Nervo; Tetitlan; San Pedro Dome; Ahuacatlan; NE of Chapalilla; SW of Ceboruco volcano (CB-1 site)
- Gravity believed to reflect the morphology of granitic basement
- Dense andesites (2.7 g/cm3) below 2000 m in CB-1
- Accuracy of Bouguer Gravity Map
    - a) Elevations +/- 10 m
    - b) Terrain corrections (always positive)
    - c) Contour projections by program

ELECTRICAL RESISTIVITY STUDIES

- Vertical Electrical Soundings (VES) - Schlumberger
  AB/2 = 500 m to AB/2 = 3000 m
- Ceboruco-San Pedro Dome-Bartolinas area: 1250 sq km
  1984-85, 78 stations; 1990-91, 107 stations; = 177 sta.
- Broad low-resistivity zone (1-10 ohm-m) between San Pedro Dome and Ceboruco volcano (generally low topography)
- High resistivity areas include most volcanoes, domes
- Identified 11 sites with major electrical conductors for drill hole locations, including: Ceboruco; Las Cuevas; Santa Isabel; Casa Blanca; Amado Nervo; Bartolinas

TEMPERATURE GRADIENT RESULTS

- 5 Gradient Holes in central area of 90 sq km

Drill Hole	Depth (m)	Ts	Tbh	Tg (C/km)
GC-1 (Santa Isabel)	150	---	43	+10
GC-2 (San Pedro)	110	34	28	-60
GC-3 (Bartolinas)	180	49	42	+96-130
GC-4 (Las Cuevas)	180	---	48	+12
GC-5 (Amado Nervo)	190	42	37	+37
• GC-? (SW Ceboruco)	400	---	46	+21
• CB-1 (SW Ceboruco)	2800	---	112	+39

EXPLORATION STRATEGY - GEOTHERMAL RESOURCES

Purpose

- Systematically apply a selected mix of exploration techniques tailored to the geologic environment and the expected geothermal resource type
- Staged exploration to minimize risk of failure
- Staged exploration to minimize cost

U S Industry Perspective

- Profit oriented - capital is at risk
- Competition for best prospects and resources
- Risk of missed resource with improper exploration
- Reduced profit with high front-end (exploration) costs
- Cost-effective exploration minimizes costs of geophysics; Cost-effective geophysics minimizes costs of drilling
- Largest costs are due to deep drilling

UURI Exploration Strategy - Developed with Industry

- EXPLORATION STRATEGY FOR HIGH-TEMPERATURE HYDROTHERMAL SYSTEMS IN BASIN AND RANGE PROVINCE - S.H. Ward, H.P. Ross, D.L. Nielson: AAPG Bulletin, 1981

- REGIONAL EXPLORATION FOR CONVECTIVE-HYDROTHERMAL RESOURCES - P.M. Wright, D.L. Nielson, H.P. Ross, J.N Moore, M.C. Adams, S.H. Ward: Geothermal Science & Technology, 1989

- STATE-OF-THE-ART GEOPHYSICAL EXPLORATION FOR GEOTHERMAL RESOURCES - P.M. Wright, S.H. Ward, H.P. Ross, R.C. West: Geophysics, 1985

CEBORUCO EXPLORATION RESULTS

REGIONAL GEOLOGY (9,000 sq km) >

  GEOLOGIC MAPPING AND HYDROTHERMAL ALTERATION (3,500 sq km) >

    DETAILED GEOLOGY AND HYDROGEOLOGY (1225 sq km) >

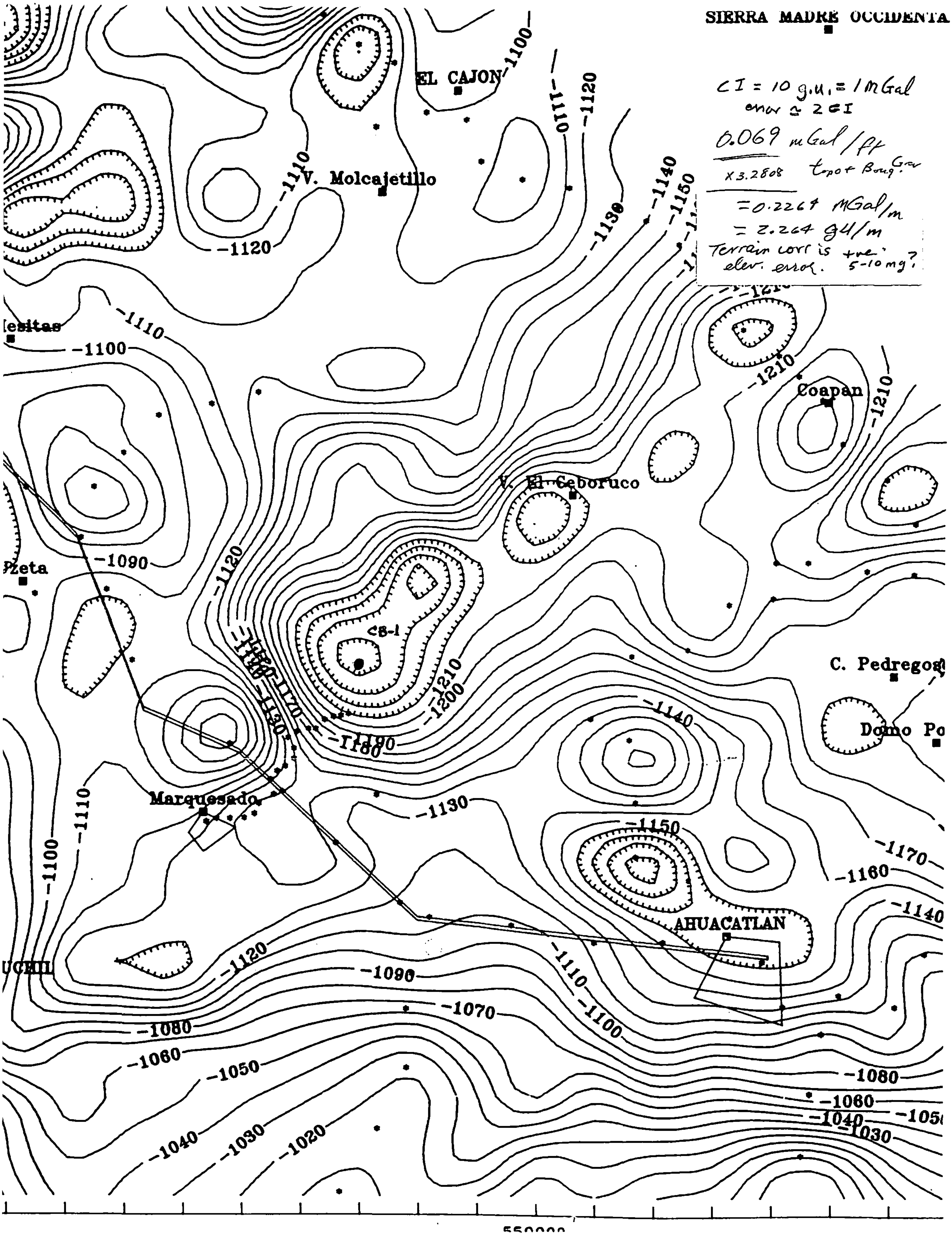
      TEPIC-ZACOALCO GRABEN AREA >

        SAN PEDRO DOME - CEBORUCO VOLCANO AREA

          CEBORUCO DRILL TEST - CB-1

PRELIMINARY CONCLUSIONS

- Area of geothermal resource potential reduced to 30 x 20 km, or about 600 sq km.
- Regional low resistivity zones complicate electrical resistivity (VES) and MT interpretations; observed in the U S Cascades, and at Long Valley, CA
- GeoEvaluaciones S.A. de C.V., MT contractor, identified 3 areas where TM, TE apparent resistivity plots suggested conductive zones to depth; possible targets: Northern Ceboruco; Amado Nervo; San Pedro
- CFE identified the SW Ceboruco area as a favorable low-resistivity zone, discounted by Geoevaluaciones
- MT data density was not sufficient to select a 2.8 km drillhole based on MT alone; Geoevaluaciones recommended 30-40 new sites per area
- 5 shallow temperature gradient holes, in central 90 sq km area. Temperatures and gradients not very encouraging.
- Temperature gradient hole at CB-1, to 400 m, not very encouraging for high temperatures at moderate depth.
- CB-1 was sited on several types of evidence: geologic-tectonic model; volcanic setting; MT low-resistivity; Bouguer gravity minimum
- Additional MT stations (20-30) and several intermediate-depth (200-400 m) temperature gradient holes are recommended before siting deep (>1000 m) exploratory wells
- Geothermal system is more restricted than first thought (CFE-GRC paper); or located elsewhere near Ceboruco volcano



CI = 10 g.u. = 1 mGal
error ≃ 2 CI

0.069 mGal/ft
×3.2808 topo + Boug. Grav

= 0.2264 MGal/m
= 2.264 gu/m
Terrain corr is +ve.
elev. error. 5-10 mg?

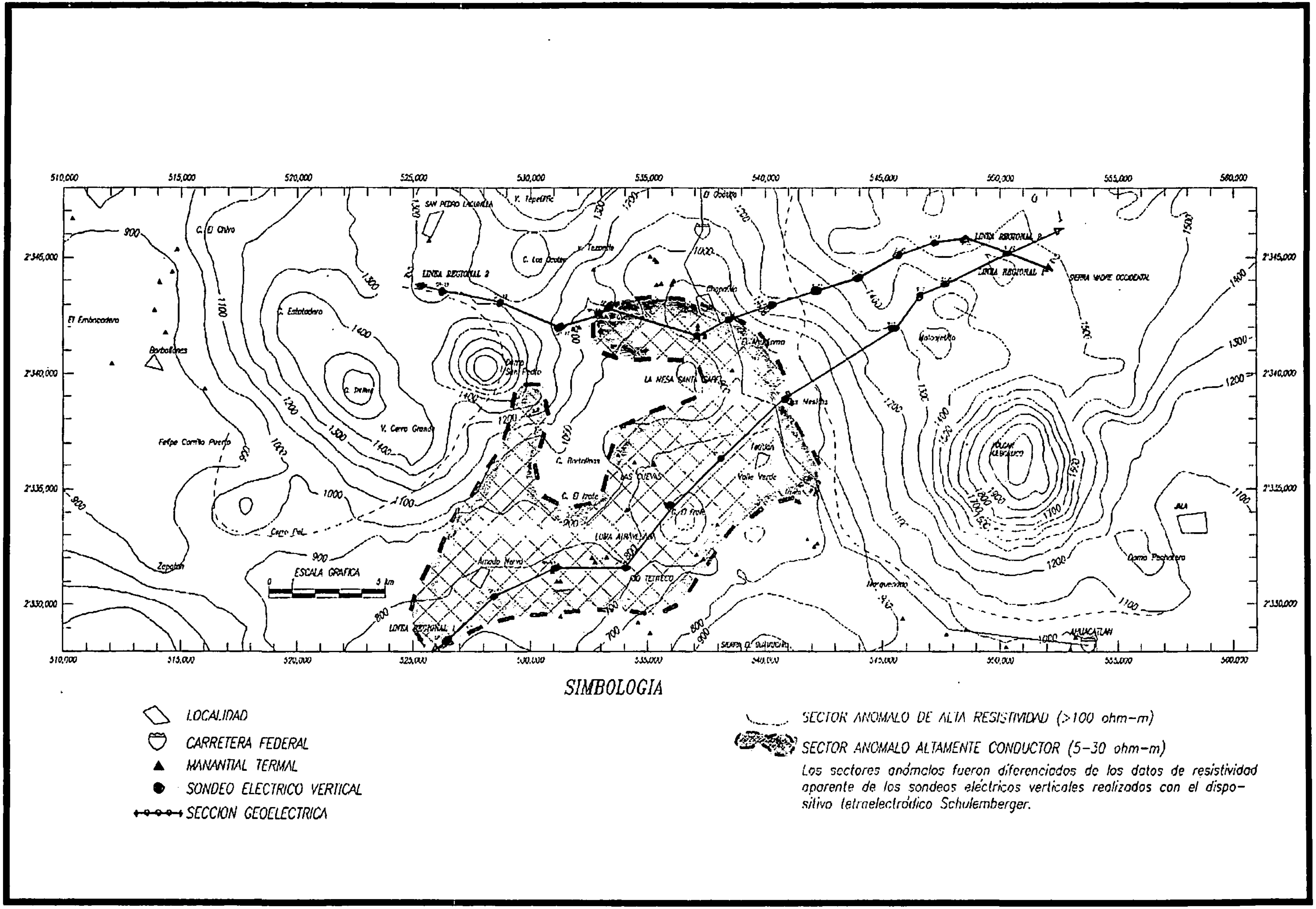


FIGURA 6.- INTEGRACION DE DATOS GEOELECTRICOS DE RESISTIVIDAD (SONDEOS ELECTRICOS VERTICALES)

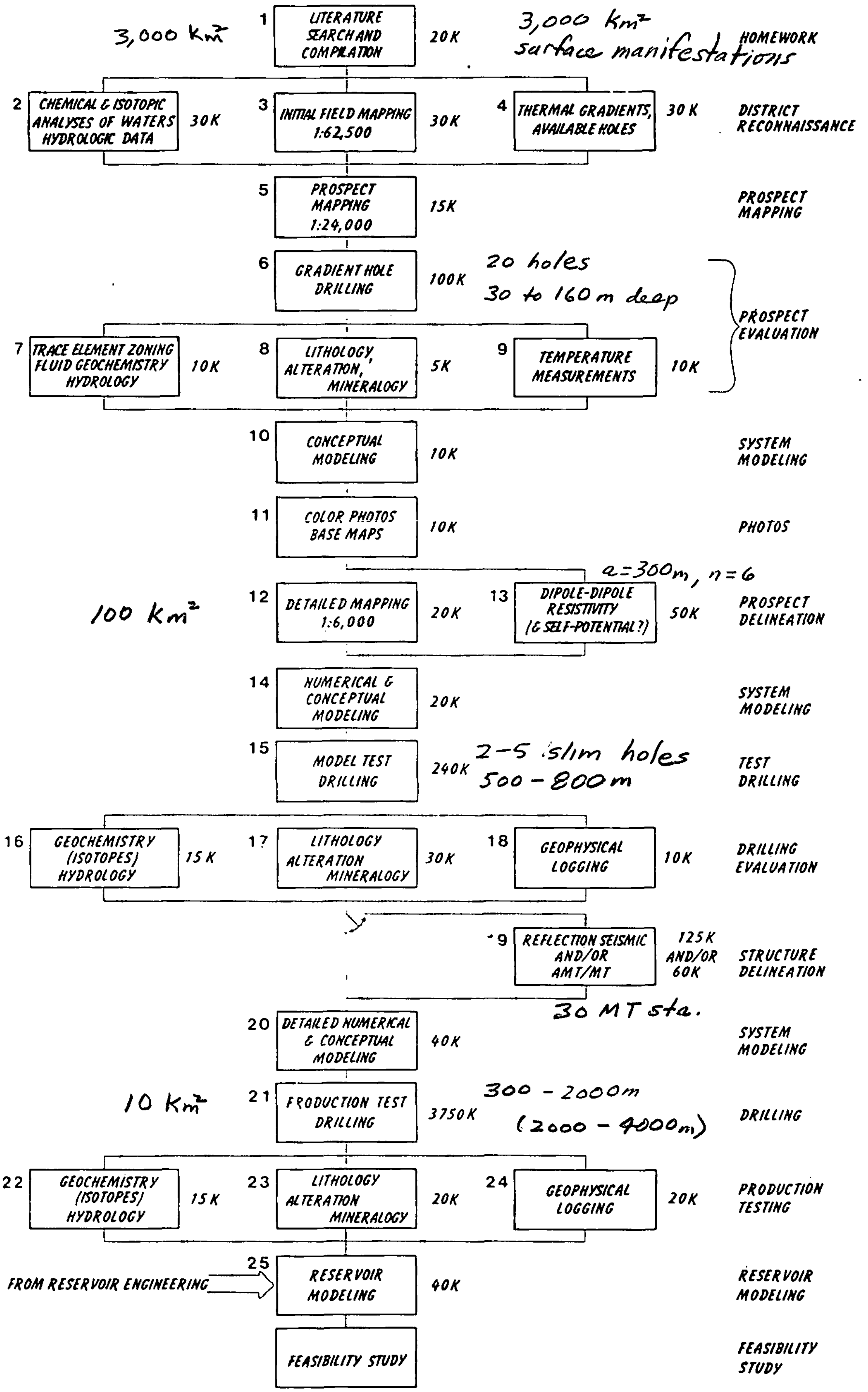


FIG. 6—Suggested high-temperature hydrothermal exploration strategy. Numbers at left of blocks indicate operating sequence. *K* numbers at right of blocks indicate estimated dollar cost in thousands.

GEOPHYSICAL STUDIES
CEBORUCO GEOTHERMAL RECONNAISSANCE AREA

Phillip E. Wannamaker, UURI   J. F. Arellano G., CFE
Howard P. Ross, UURI

Background

- Ceboruco area, western Neovolcanic Belt, identified by CFE as a promising geothermal area from geologic, geochemical, geophysical studies
- Extensive geophysical program, 1983-1992; ending with 90 MT stations
- CB-1 drilled to 2,800 m; T max. = 112 C

Program for 1994

- Review and critique MT data and interpretation (UURI)
- Complete new MT modeling/interpretation, as needed (UURI and CFE)
- Review supporting geologic and geophysical data (UURI)
- Review Ceboruco exploration strategy (UURI)

CEBORUCO - GEOPHYSICAL STUDIES

Data Reviewed

- Regional Geology, Tepic-Zacoalco Graben, Nayarit
- El Ceboruco Geothermal Project, State of Exploration
- Gravity Studies, and Bouguer Anomaly Map
- Regional Aeromagnetic Studies
- Integration of Electrical Resistivity Studies
- Magnetotelluric Data, and Interpretations
- CB-1: Lithologic Column and Temperature Results

Problems Encountered

- Schedules - P. Wannamaker, H. Ross, GRC
- Report review - Spanish to English
- Correspondence and discussion
- GEOTOOLS
- Location of CB-1 uncertain to UURI
- GeoEvaluaciones MT Plates 1-14 not available
- GeoEvaluaciones MT Plot Ceboruco-s24 missing

VIEWGRAPHS - TOPICS

1 Introduction- program, problems, data
2 Location map
3 Exploration strategy
4 Exploration Strategy - U S Industry
5 Exploration Strategy - Ceboruco
6 Results: magnetics, gravity, electrical resistivity
7 Comments and Questions - Ceboruco
8 MT Interpretation: Geoevaluacions vs CFE
9 MT Interpretation: Data density for MT stations - map
10-X: MT Interpretation: Phil

EXPLORATION STRATEGY - GEOTHERMAL RESOURCES

Purpose

- Systematically apply a selected mix of exploration techniques tailored to the geologic environment and the expected geothermal resource type
- Staged exploration to minimize risk of failure
- Staged exploration to minimize cost

U S Industry Perspective

- Profit oriented - capital is at risk
- Competition for best prospects and resources
- Risk of missed resource with improper exploration
- Reduced profit with high front-end (exploration) costs
- Cost-effective exploration minimizes costs of geophysics; Cost-effective geophysics minimizes costs of drilling
- Largest costs are due to deep drilling

UURI Exploration Strategy - Developed with Industry

- EXPLORATION STRATEGY FOR HIGH-TEMPERATURE HYDROTHERMAL SYSTEMS IN BASIN AND RANGE PROVINCE - S.H. Ward, H.P. Ross, D.L. Nielson: AAPG Bulletin, 1981

- REGIONAL EXPLORATION FOR CONVECTIVE-HYDROTHERMAL RESOURCES - P.M. Wright, D.L. Nielson, H.P. Ross, J.N Moore, M.C. Adams, S.H. Ward: Geothermal Science & Technology, 1989

- STATE-OF-THE-ART GEOPHYSICAL EXPLORATION FOR GEOTHERMAL RESOURCES - P.M. Wright, S.H. Ward, H.P. Ross, R.C. West: Geophysics, 1985

CEBORUCO EXPLORATION RESULTS

REGIONAL GEOLOGY (9,000 sq km) >

GEOLOGIC MAPPING AND HYDROTHERMAL ALTERATION (3,500 sq km) >

DETAILED GEOLOGY AND HYDROGEOLOGY (1225 sq km) >

TEPIC-ZACOALCO GRABEN AREA >

SAN PEDRO DOME - CEBORUCO VOLCANO AREA

CEBORUCO DRILL TEST - CB-1

GEOPHYSICAL SUMMARY

AEROMAGNETICS

* Regional data, 6,000 sq km
* Extensive processing, analytical operations
* Interpretation confirms NW-SE, NE-SW trends proposed by photogeologic interpretation
* Zones of low magnetization correspond to hydrothermal alteration
* 2-D Model of magnetic basement at 800 - 1200 m
* Indicates a zone of granitic basement

REGIONAL GRAVITY STUDIES

* 450 sq km; 120 stations at 1 km spacing
* To assist in structural interpretation and morphology of "basement"
* Includes zones of interest from electrical resistivity (VES) and magnetotelluric (MT) data
* Bouguer Gravity Anomaly map defines 5 NW-SE lineaments, and 2 NE-SW trends
* Several gravity minima, including: Amado Nervo; Tetitlan; San Pedro Dome; Ahuacatlan; NE of Chapalilla; SW of Ceboruco volcano (CB-1 site)
* Gravity believed to reflect the morphology of granitic basement
* Dense andesites (2.7 g/cm3) below 2000 m in CB-1
* Accuracy of Bouguer Gravity Map
  a) Elevations +/- 10 m
  b) Terrain corrections (always positive)
  c) Contour projections by program

ELECTRICAL RESISTIVITY STUDIES

* Vertical Electrical Soundings (VES) - Schlumberger AB/2 = 500 m to AB/2 = 3000 m
* Ceboruco-San Pedro Dome-Bartolinas area: 1250 sq km 1984-85, 78 stations; 1990-91, 107 stations; = 177 sta.
* Broad low-resistivity zone (1-10 ohm-m) between San Pedro Dome and Ceboruco volcano (generally low topography)
* High resistivity areas include most volcanoes, domes
* Identified 11 sites with major electrical conductors for drill hole locations, including: Ceboruco; Las Cuevas; Santa Isabel; Casa Blanca; Amado Nervo; Bartolinas

TEMPERATURE GRADIENT RESULTS

- 5 Gradient Holes in central area of 90 sq km

Drill Hole	Depth (m)	Ts	Tbh	Tg (C/km)
GC-1 (Santa Isabel)	150	---	43	+10
GC-2 (San Pedro)	110	34	28	-60
GC-3 (Bartolinas)	180	49	42	+96-130
GC-4 (Las Cuevas)	180	---	48	+12
GC-5 (Amado Nervo)	190	42	37	+37
* GC-? (SW Ceboruco)	400	---	46	+21
* CB-1 (SW Ceboruco)	2800	---	112	+39

PRELIMINARY CONCLUSIONS

- Area of geothermal resource potential reduced to 30 x 20 km, or about 600 sq km.

- Regional low resistivity zones complicate electrical resistivity (VES) and MT interpretations; observed in the U S Cascades, and at Long Valley, CA

- GeoEvaluaciones S.A. de C.V., MT contractor, identified 3 areas where TM, TE apparent resistivity plots suggested conductive zones to depth; possible targets:
  Northern Ceboruco; Amado Nervo; San Pedro

- CFE identified the SW Ceboruco area as a favorable low-resistivity zone, discounted by Geoevaluaciones

- MT data density was not sufficient to select a 2.8 km drill hole based on MT alone; Geoevaluaciones recommended 30-40 new sites per area

- 5 shallow temperature gradient holes, in central 90 sq km area Temperatures and gradients not very encouraging.

- Temperature gradient hole at CB-1, to 400 m, not very encouraging for high temperatures at moderate depth.

- CB-1 was sited on several types of evidence:
  geologic-tectonic model; volcanic setting;
  MT low-resistivity; Bouguer gravity minimum

- Additional MT stations (20-30) and several intermediate-depth (200-400 m) temperature gradient holes are recommended before siting deep (>1000 m) exploratory wells

- Geothermal system is more restricted than first thought (CFE-GRC paper); or located elsewhere near Ceboruco volcano

MT contractor computed appropriate two-dimensional (2-D) models, and new numerical modeling was not deemed necessary. UURI was unable to obtain the necessary software in time to use the GEOTOOLS formated MT data submitted by CFE.

A second interpretation of the MT data was completed by CFE geophysicists. This interpretation called attention to several MT stations SW of Ceboruco volcano which suggested a larger conductivity-thickness body at depth. These stations had not been identified by GeoEvaluaciones as a promising target area because they did not exhibit a response typical of conductive bodies going to depth, and were believed to be part of the region-wide conductive horizon. Decreases in apparent resistivity observed for periods longer than 1 to 10 seconds are due to the regional, mid-crustal state, with some short scale data variations caused by minor static shifts, or data noise.

Dr. Ross reviewed the aeromagnetic and gravity data, and noted that extensive state-of-the-art processing had been applied to the aeromagnetic data. A final, geometric interpretion of magnetic bodies and geologic structures was not noted, however.

The gravity survey is described as a reconnaissance level survey which probably was restricted to existing roads and trails. The locations of gravity stations were determined by vehicle odometer (+/- 100 m), and station elevations were estimated from contour maps (estimated to be +/-10 m). It does not appear that terrain corrections were applied to the data, and these could be quite significant (1-3 mGal, 10-30 g.u.) near Ceboruco volcano. Elevation errors could result in errors of as much as 2.2 mGals (22 g.u.). Another limitation of the Bouguer gravity map, especially in the area near CB-1, is the relatively low data density. Although the automated contour interpolation routine may provide the best estimate of gravity contours, it <u>could</u> lead to considerable error in areas of low data density, especially when using data which may be in error due to elevation errors and without terrain corrections. Thus the gravity map may be useful in projecting regional geologic features, but may be inappropriate for use in drill site selection.

Plans for 1995

1. Additional detailed MT interpretation could be undertaken if specific interpretation problems are identified by CFE geophysicists, such as evaluating proposed drill targets.

2. UURI suggests a detailed evaluation of the accuracy of the Bouguer gravity map for an area of approximately 100 sq km, including the large gravity low which extends southwest from Ceboruco volcano. Gravity data should be obtained at 25 to 50 stations, well distributed between the existing stations. Positions and elevations should be accurately determined for these and nearby existing stations (GPS control?) and full terrain corrections should be applied.

New Villhow CB-3 Guarinas

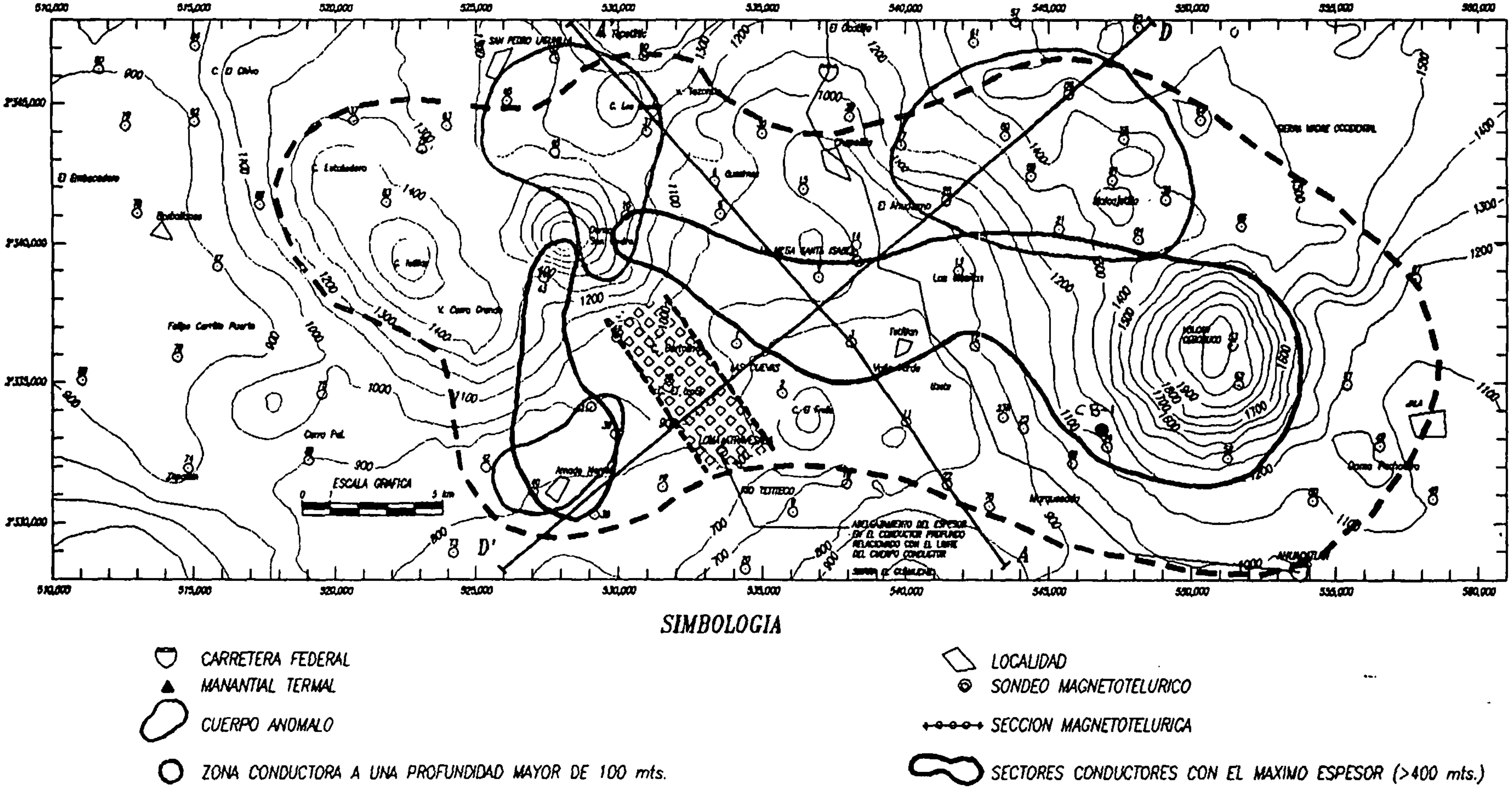
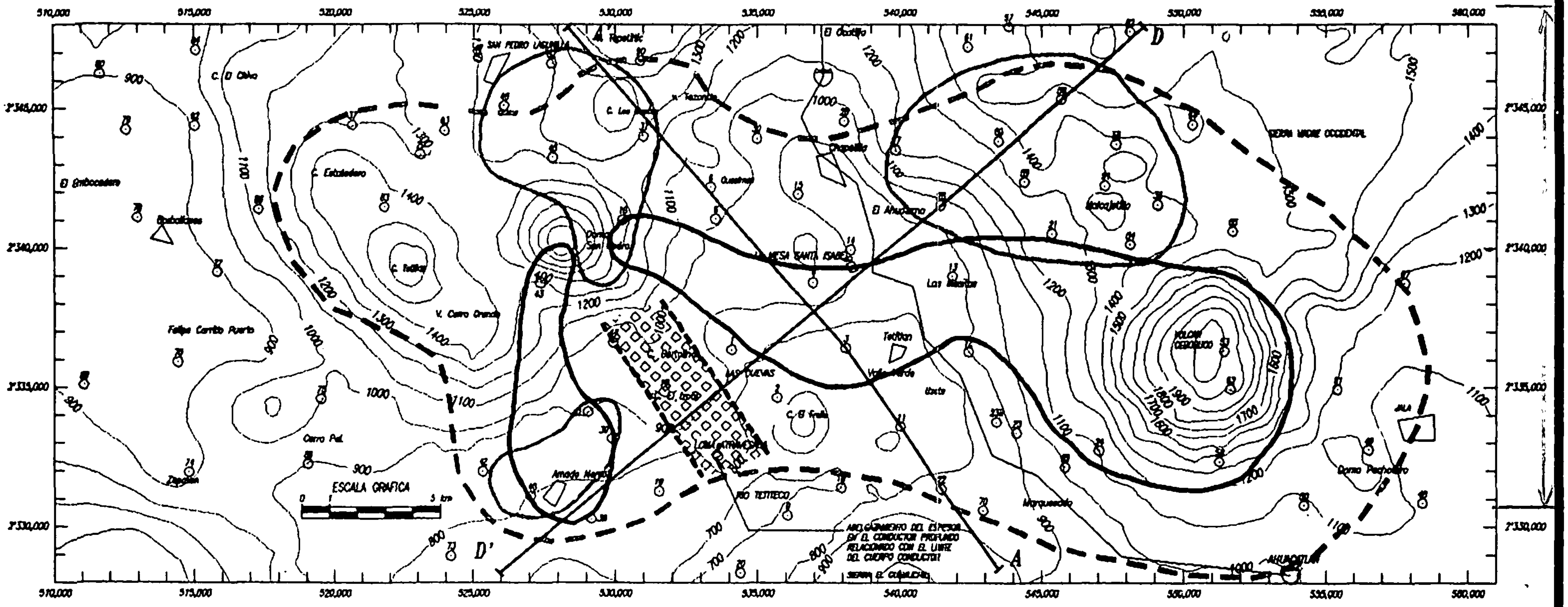


FIGURA 8.- SECTORES GEOELECTRICAMENTE ANOMALOS DE ACUERDO CON LOS DATOS MAGNETOTELURICOS

[illegible] Cb-3 [illegible]



SIMBOLOGIA

- CARRETERA FEDERAL
- ▲ MANANTIAL TERMAL
- CUERPO ANOMALO
- ○ ZONA CONDUCTORA A UNA PROFUNDIDAD MAYOR DE 100 mts.
- LOCALIDAD
- ◎ SONDEO MAGNETOTELURICO
- SECCION MAGNETOTELURICA
- SECTORES CONDUCTORES CON EL MAXIMO ESPESOR (>400 mts.)

Signal-to-Noise ratio - the ratio of that portion of the recorded, digitized and processed electric or magnetic field data that will produce valid MT results to that portion that will not. This is a particularly difficult factor to determine in MT as there are forms of noise that are very difficult to distinguish from the natural electromagnetic wave that will yield proper MT results.

Skew - a measure of the agreement of the computed resistivity tensor with the theoretical assumption of two-dimensional behavior, defined as

$$\frac{(\rho_{xx} + \rho_{yy})}{(\rho_{xy} - \rho_{yx})}$$

where the ρ items are as defined for the Resistivity Tensors.

Skin depth - an electromagnetic wave propagating into the earth (or any material other than vacuum) is attenuated with distance. The skin depth is defined as that depth where the amplitude of the wave has been attenuated to 1/e of its original value.

Stacking - in MT data processing the combination of several discrete data samples. Stacking is usually performed in the frequency domain, after the Fourier Transform has been applied to the time series but before the tensor resistivity calculations have been performed. Stacking improves data quality in that coherent signal should add constructively in the combination process, while random noise should tend to cancel. MT stacking is analogous to Vibroseis sweep stacking in seismic exploration.

Statics - the effects on MT data of shallow lateral resistivity variations. Statics effects can influence MT data throughout the frequency range.

TE, TM - refer to Transverse Electric and Transverse Magnetic wave propagation nodes, terms borrowed from electrical engineering parlance. TE refers to electric field (and apparent resistivity) parallel to strike, while TM refers to electric field perpendicular to strike. Strictly speaking, TE and TM nodes are only defined for a two-dimensional geometry.

Tensor Resistivity - see Resistivity Tensor. The Tensor Resistivities are the ρ_{xy} and ρ_{yx} terms of the Resistivity Tensor.

Three-Dimensional Structures - structures where the resistivity may vary vertically and in any horizontal direction.

Reference angle - the horizontal azimuth, usually true north, that is the reference for the resistivity tensor and tipper rotation angles. The reference angle may or may not be the same as the measurement angle, the angle that the sensors are installed at at the site.

Reference MT - the technique whereby MT data is acquired simultaneoulsy at two or more sites, with the data at each site processed using one or more of the other sites in an effort to improve the signal-to-noise ratio utilizing correlation techniques.

Resistivity - the electrical property of a material, measured in ohm-meters, that is determined by MT. (See also apparent resistivity and inverted resistivity.)

Resistivity contrast - see contrast.

Resistivity Tensor - the mathematical expression

$$\begin{vmatrix} \rho_{xx} & \rho_{xy} \\ \rho_{yx} & \rho_{yy} \end{vmatrix}$$

that relates the electric and magnetic fields at the surface of the earth.

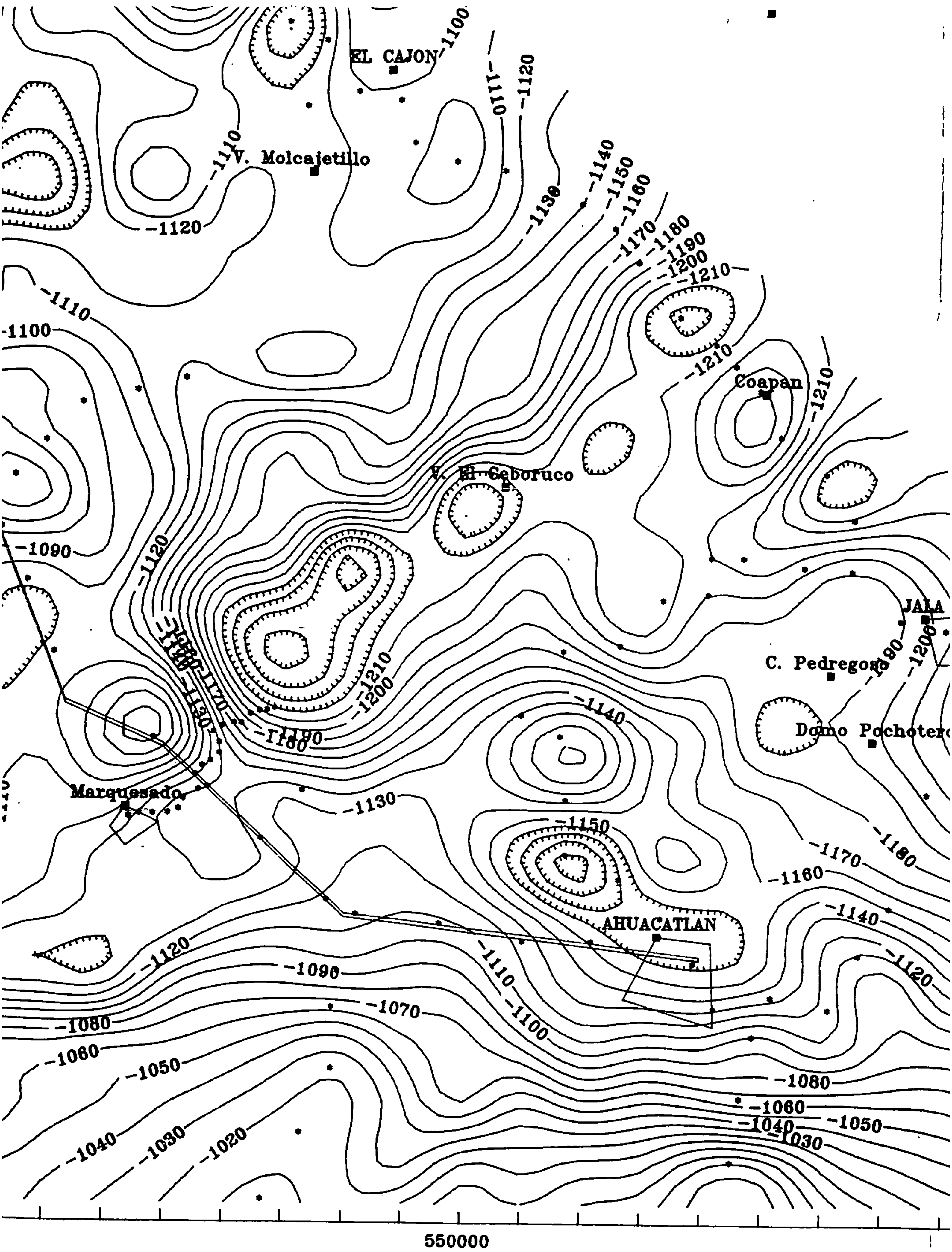
Rotated Apparent Resistivity - the ρ_{xy} and ρ_{yx} terms of the relationship

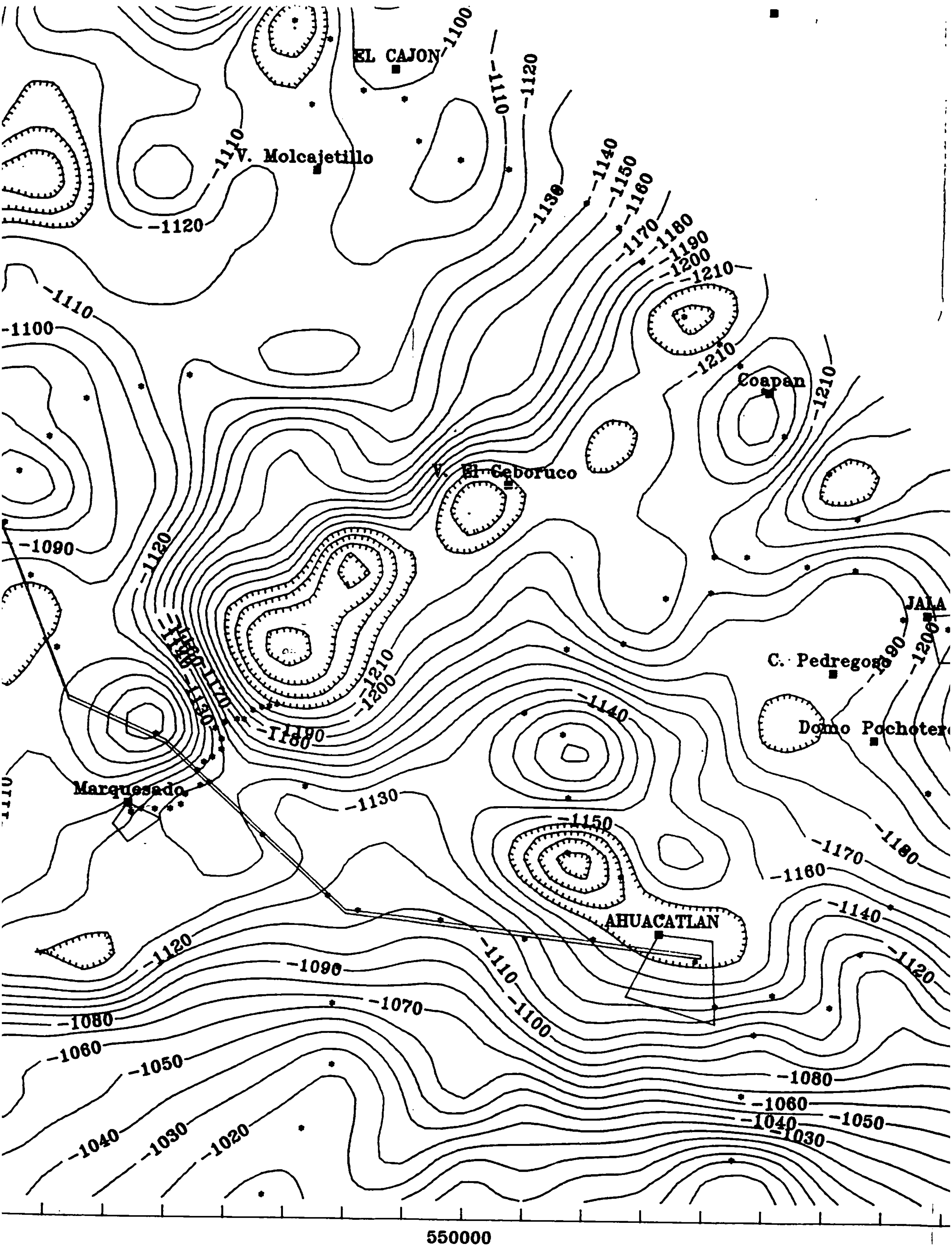
$$Ex = \rho_{xx} Hx + \rho_{xy} Hy$$
$$EY = \rho_{yx} Hx + \rho_{yy} Hy$$

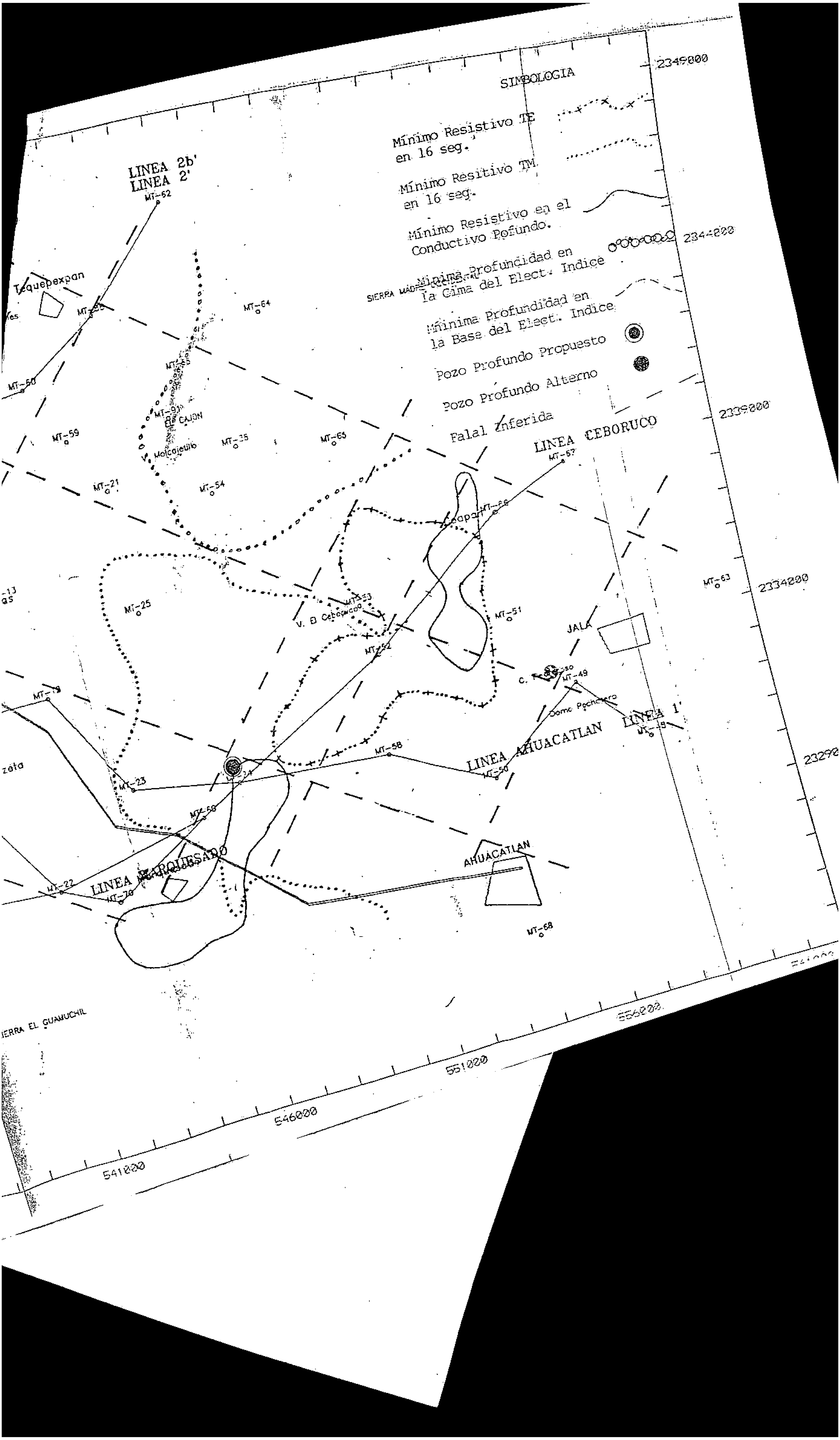
where the xy coordinate system has been rotated mathematically from the measurement coordinate system to an orientation where ρ_{xy} or ρ_{yx} is a maximum (and ρ_{yx} and ρ_{xy} is a minimum). An alternate approach is to minimize ρ_{xx} and ρ_{yy}.

Rotation angle - the azimuth to which the resistivity tensor is rotated in the computation of rotated apparent resistivity.

Scaler resistivity - the apparent resistivity computed for an isotropic earth where there is no variation of apparent resistivity with measurement or calculation azimuth. Also the apparent resistivity(ies) calculated using the horthogonal electric and magnetic fields along the measurement axes. This latter are sometimes called the "Cagniard" resistivities, after the original MT paper in Geophysics in 1953.


EL CAJON
-1100
-1110
-1120
-1110
V. Molcajetillo
-1120
-1130
-1140
-1150
-1160
-1170
-1180
-1190
-1200
-1210
-1110
-1100
-1210
Coapan
-1210
V. El Ceboruco
-1090
-1120
JALA
-1200
-1190
C. Pedregoso
-1150
-1130
-1170
-1180
-1190
-1200
-1210
-1140
Domo Pochotero
Marquesado
-1130
-1150
-1170
-1180
-1160
AHUACATLAN
-1140
-1120
-1090
-1110
-1120
-1070
-1080
-1100
-1060
-1050
-1080
-1060
-1040
-1050
-1030
-1040
-1030
-1020
550000


-1100
EL CAJON
-1110
-1120
-1110
V. Molcajetillo
-1120
-1130
-1140
-1150
-1160
-1170
-1180
-1190
-1200
-1210
-1110
-1100
-1210
Coapan
-1210
V. El Ceboruco
-1090
-1120
-1210
-1200
-1190
-1180
-1170
-1130
JALA
-1200
-1190
C. Pedregoso
-1140
Domo Pochotero
Marquesado
-1130
-1150
-1170
-1180
-1160
AHUACATLAN
-1140
-1120
-1090
-1110
-1120
-1070
-1080
-1100
-1060
-1050
-1080
-1060
-1050
-1040
-1030
-1040
-1030
-1020
550000


SIMBOLOGIA
Mínimo Resistivo TE en 16 seg.
Mínimo Resitivo TM en 16 seg.
Mínimo Resistivo en el Conductivo Pofundo.
Mínima Profundidad en la Cima del Elect. Indice
Mínima Profundidad en la Base del Elect. Indice
Pozo Profundo Propuesto
Pozo Profundo Alterno
Falal Inferida
2349000
2344000
2339000
2334000
2329
541000
546000
551000
556000
LINEA 2b'
LINEA 2'
MT-62
Tequepexpan
MT-55
MT-64
MT-65
MT-50
MT-91
EL CAJON
MT-59
V. Molcajetillo
MT-35
MT-63
MT-21
MT-54
LINEA CEBORUCO
MT-57
SIERRA MADRE OCCIDENTAL
Coapan
MT-66
MT-13
MT-25
MT-53
V. El Ceboruco
MT-51
MT-52
JALA
C. Pedregoso
MT-49
Domo Pochetero
LINEA 1'
MT-48
LINEA AHUACATLAN
MT-19
MT-58
MT-56
MT-23
MT-24
MT-60
LINEA MARQUESADO
MT-22
MT-70
AHUACATLAN
MT-68
SIERRA EL GUAMUCHIL
zata

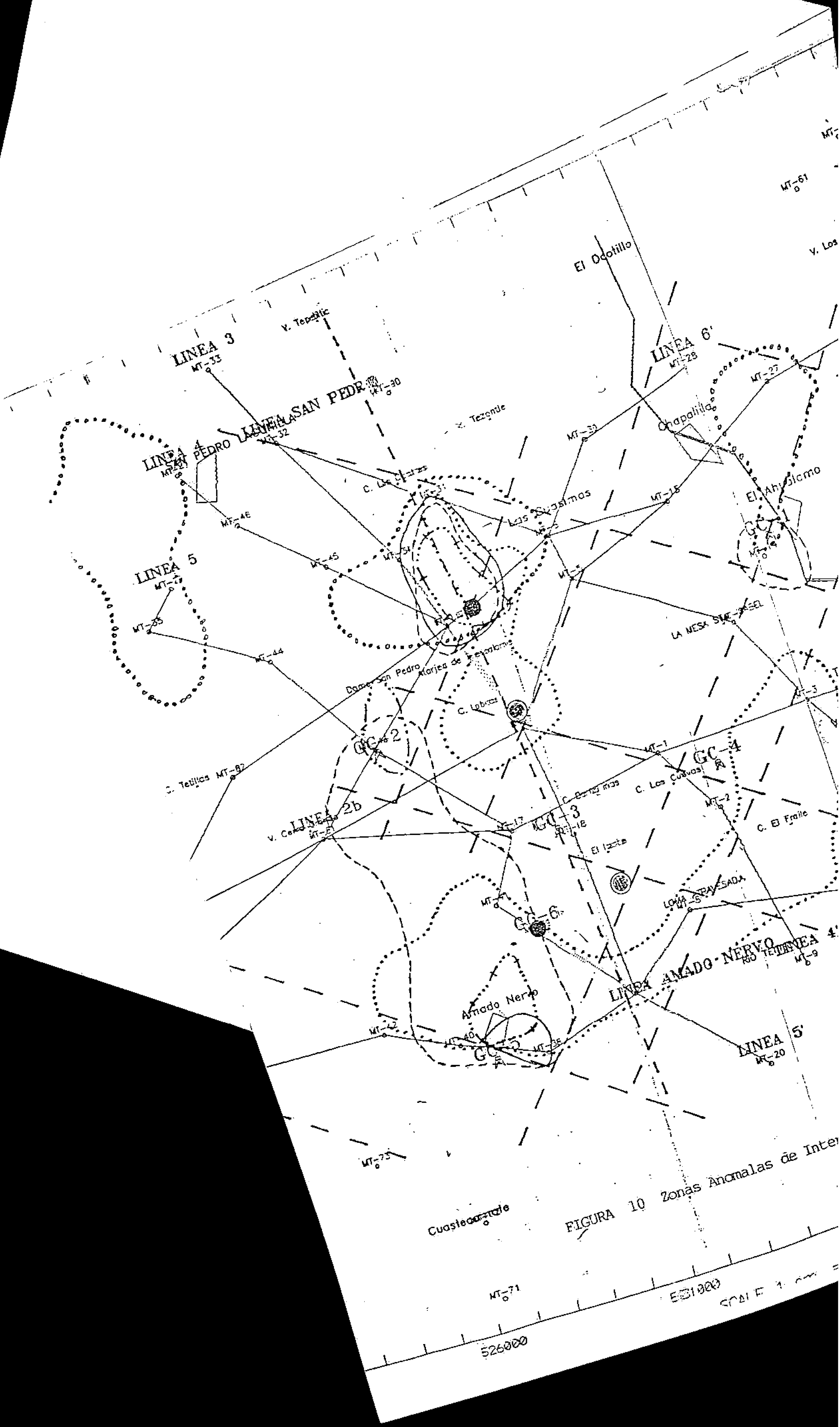


FIGURA 10 Zonas Anomalas de Inter

The DOE - CFE

Geothermal Research Program

DOE - CFE Geothermal Agreement

Effective Date: ?

Duration: 1-5 years

Major Objectives:

- To achieve a thorough understanding of the nature of geothermal reservoirs in sedimentary and fractured igneous rocks.
- To investigate how geothermal resources can best be explored and exploited.
- To exchange information on geothermal topics of mutual interest.

Agreement Coordinators:

- Dr. Gerardo Hiriart (CFE)
- Dr. Ted Mock (DOE)

AREAS OF FOCUS

- Geologic and hydrogeologic studies, including analysis of core samples, cuttings, and well logs.
- Geophysical studies, including geophysical surveys and downhole mapping of natural fractures.
- Sampling, monitoring, and modeling of reservoir behavior.
- Reinjection of waste water, including isotopic tracer tests.
- Characterization of subsidence and induced seismicity.
- High temperature materials testing, scaling, and corrosion study and control.
- Technology for drilling and completion of geothermal production and injection wells.
- Non-electrical applications as a secondary benefit for steam production.
- Other related areas as mutually agreed upon.

TASKS

1. Geology and Hydrogeology
2. Geophysics
3. Reservoir Engineering
4. Reinjection
5. Subsidence and Induced Seismicity
6. Geochemical Engineering and Materials
7. Information Exchange

UURI

University of Utah Research Institute
Earth Science Laboratory
391 Chipeta Way, Suite C
Salt Lake City, UT 84108-1295
USA

Phone: 801-584-4422 FAX: 801-584-4453

Facsimile (FAX) Cover Page

From: Howard Ross Date: November 22, 1994

To: Ingr. Jose Francisco Arellano G.
FAX: (011) 524-314-4735

Number of pages including this one: **3**

Message or Comments:

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108–1295
TELEPHONE 801-524-3422

November 22, 1994

Ingr. Jose Francisco Arellano G.
Jefe, Ofna. De Geofisica
Departmento De Exploracion
Comision Federal De Electricidad
Gerencia De Proyectos Geothermoelectricos
Morelia, Michoacan
Mexico

Dear Jose:

Joeseph Moore and I certainly enjoyed the Third Technical Meeting of the DOE-CFE Geothermal Agreement in Mexicali, Baja California on November 15. I especially enjoyed our personal discussion of the more recent geophysical work completed by CFE, the drilling results of CB-2 and CB-3, and plans for future geophysical work and analysis in the Ceboruco reconnaissance area. I regret that I did not know about your improved Bouguer gravity map befor the meeting.

I discussed you questions regarding MT data and interpretation with Dr. Wannamaker before he left for the Antartic on November 18. Philip says that the tipper phase, tipper magnitude, tipper strike, E multiple coherency, HZ multiple coherency, impedance skew, and other MT parameters could be requested from the MT contractor; they may fill 1 to 2 disketts in ASCII format. Coherency and skew are now less often used as a measure of noise, especially if a remote reference is used in the survey. These parameters are used mainly to evaluate data quality, and perhaps for 3-dimensional effects. From our reading of the Ceboruco report, it appears that the contractor has examined these data.

In most of his routine interpretations, Wannamaker checks the error bars on the TE and TM mode apparent resistivity plots to evaluate data quality and dimensionality. If there are quality or interpretation problems he would then examine the other parameters in more detail. He says that you could certainly compute tipper, skew and other parameters to use in verification of numerical modeling, but this is not generally done. He emphasizes that even if a conductive body is indicated, the main interpretation problem is to determine if the conductive body is a regionally altered volcanic unit, or is more specifically related to the presence of a geothermal system.

I think it would be beneficial for you to visit UURI and discuss MT interpretation in more detail with Dr. Wannamaker. Perhaps you could bring specific problem MT data or models to discuss. He will return to Salt Lake City in late January 1995, and would then need some time to address other problems. He suggests that the best time for discussions would be about March 1995.

As you know, several geothermal researchers are working with geothermal simulators for reservoir modeling, and have published results in the GRC Transactions (i.e. Elliot Yearsley, David Faulder, and G. Mike Shook). Two other researchers who have been working on combined conductive-convective heat transfer modeling without the full reservoir simulation are:

Dr. William D. Gosnold
Department of Geology and Geological Engineering
University of North Dakota
Box 8068, University Station
Grand Forks, North Dakota 58202
Tel. (701) 777-2631 FAX (701) 777-4838

Dr. Henry P. Heasler
Department of Geology and Geophysics
University of Wyoming
P.O. Box 3006
Laramie, Wyoming 82071-3006
Tel. (307) 766-4200 FAX (307) 766-2737

Gerado Garcia E. may wish to contact these researchers to determine the status of their heat flow studies.

Sincerely,

Howard Ross

Howard P. Ross
Section Head/Applied Geophysics

To: J. N. Moore UURI Fax: 801-584-4453
P.E. Wanamaker
H.P. Ross
G.D. Nash
M. Wright

DOE-CFE Geothermal Agreement

Final Notice Plus One
Third Technical Meeting
Mexicali, Baja Cal
15-16 November 1994

Due to an inability of our Mexican colleagues to travel to San Diego at this time, the Third Technical Meeting will be held in Mexicali, Baja Calif instead of the Ramada - Old Town Hotel in San Diego. A block of rooms is being held at the De Anza Hotel in Calexico, CA at a rate of $35 per night for Monday and Tuesday nights. For reservations, call: (619) 357-1112. The Agenda for the meeting has not changed.

The De Anza Hotel is 3 short blocks from the border crossing. The meeting will be hosted by CFE on both days at the Colonial Hotel in Mexicali. CFE staff will pick us up at the Del Norte Hotel (just across the border) on both days at 0830 for transfer to the Colonial.

confirmed to Paul by phone 11/10/94 10:35 am

Please cancel your reservation at the Ramada-Old Town if you have one and transfer it to the De Anza (or other hotel of your choice in Calexico or El Centro). Please confirm your participation to Ted Mock (Tel/Fax: 202-586-5340/5124) or Paul Kruger (Tel/Fax: ~~8~~14- 415 725-2382/8662).

Post-it™ Fax Note 7671		Date 17 Oct 94	# of pages ▸ 4
To Joe Moore		From P. Kruger	
Co./Dept. UURI		Co. SGP	
Phone #		Phone #	
Fax # 801-584-4453		Fax # 415-725-8662	

Copies for:

Joe Moore
PE Wanamaker
HP Ross
GD Nash
M. Wright

Guzman
H
German
H

DOE-CFE Geothermal Agreement

Final Notice
Third Technical Meeting
San Diego, CA
15-16 November 1994

At the Administrative Meeting of the Agreement Coordinators on 3 October 1994 in Salt Lake City, the following accords were reached with respect to the Third Technical Meeting:

(1) The meeting will be held at the Ramada - Old Town Hotel in San Diego. A block of rooms is being held for the "Geothermal" meeting at a rate of $59 per night for Monday and Tuesday nights. For reservations, call: (800) 255-3544. The Agenda for the meeting is attached.

(2) The order of Presentations by the Co-Principal Investigators is by the List of Joint Projects for 1994 followed by New Projects for 1995. The revised List of Joint Projects is attached.

(3) The Coordinators request that the Co-Principle Investigators prepare a two-page Progress Report for the Meeting which includes a Background to the project, the planned scope of the project for 1994, a summary of results to date, and plans for 1995. A suggested format for the 2-page report is attached.

(4) It was agreed that there would be one further technical meeting (next Spring) and that Final Reports would be due for the current DOE-CFE Agreement projects. This will be discussed at the Third Technical Meeting.

DOE-CFE Geothermal Agreement

THIRD TECHNICAL MEETING

San Diego, CA
15-16 November 1994

pick up @ 8:30 am

AGENDA

15 November 1994

9:05 am I. Introductions by Agreement Coordinators:
John E. Mock and Gerardo Hiriart

9:30 am II. Presentations by Co-Principal Investigators
in order of List of Projects (14 Nov 94)

3:30 III. Presentations of New Projects for 1995

4:30 IV. Summary by Agreement Coordinators.
5:00 Review of Agreement
Status of Agreement Renewal
Plans for Fourth Technical Meeting

16 November 1994

9:00 Meeting of Project Co-Principal Investigators on:
11:00 Results for 1994
Plans for 1995
Preparations for Final Report at Fourth Annual Meeting

Cross Border @ 12:00 ←
Lv. Calexico @ 12:15
Lv. El Centro @ 1:00

Arr - Avis Car Rental @ 3:15
Arr - S.D. Airport at 3:45

→ Lv: S.D. airport @ 4:25

DOE-CFE Geothermal Agreement

Third Technical Meeting
15-16 November 1994

Joint Projects for 1994

9:30 Cerro Prieto and Los Azufres

1. Analysis of the Behavior of Wells from Different Areas of the Cerro Prieto Geothermal Field.
    - M.J. Lippmann, LBL H. Gutierrez P., CP
    - A.H. Truesdell, Cons.

10:00 2. Chemical Reservoir Engineering at Five Los Azufres Production Wells.
    - P. Kruger, SGP L. Quijano, Ger
    - E. Sanchez, LAz

10:30 3. Direct Utilization of Geothermal Energy at Cerro Prieto and Los Azufres.
    - J.W. Lund, OIT M.A. Rangel, Ger

New Fields

11:00 4. Geochemical Studies - Tres Virgenes Geothermal Field.
    - J.N. Moore, UURI S. Venegas S., Ger

11:30 5. Geophysical Studies - Ceboruco Geothermal Reconnaissance Area.
    - P.E. Wanamaker, UURI J.F. Arellano G., Ger
    - H.P. Ross, UURI

12:00

Lunch

1:30 6. Feasibility Study for Using Excess Geothermal Power Capacity to Manufacture Hydrogen at Tres Virgenes.
    - M. Fioravanti, SGP C. Cadenas, Ger
    - P. Kruger, SGP

General Studies

2:00 7. The Joint Testing of Remote Sensing Techniques and Equipment for Use in Geothermal Exploration.
    - G.D. Nash, UURI G. Ramirez, Ger

2:30 8. Hydrogen Sulfide Gas Abatement for CFE Geothermal Plants.
    - G. Sharp, Cons. B. Terrazas, CP
    - G. Horton, Unocal

3:00

New Projects for 1995

3:30 1. Biphase Conversion Technology
    - L. Hayes, Biphase Engr. A. Oropeza, Ger

4:00 2. Modeling of Cerro Prieto with TETRAD
    - M. Shook, EG&G M. Ribo, Ger.

4:30 —

DOE-CFE Geothermal Agreement

PROJECT TITLE

Co-Principal Investigators
Affiliations

PROGRESS REPORT for 1994

Introduction

Background of the Project and review of Prior Efforts under the DOE-CFE Agreement.

Planned Scope of Project for 1994

Results to Date (Summary)

Plans for 1995

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

November 22, 1994

Ingr. Jose Francisco Arellano G.
Jefe, Ofna. De Geofisica
Departmento De Exploracion
Comision Federal De Electricidad
Gerencia De Proyectos Geothermoelectricos
Morelia, Michoacan
Mexico

Dear Jose:

Joeseph Moore and I certainly enjoyed the Third Technical Meeting of the DOE-CFE Geothermal Agreement in Mexicali, Baja California on November 15. I especially enjoyed our personal discussion of the more recent geophysical work completed by CFE, the drilling results of CB-2 and CB-3, and plans for future geophysical work and analysis in the Ceboruco reconnaissance area. I regret that I did not know about your improved Bouguer gravity map befor the meeting.

I discussed you questions regarding MT data and interpretation with Dr. Wannamaker before he left for the Antartic on November 18. Philip says that the tipper phase, tipper magnitude, tipper strike, E multiple coherency, H2 multiple coherency, impedance skew, and other MT parameters could be requested from the MT contractor; they may fill 1 to 2 disketts in ASCII format. Coherency and skew are now less often used as a measure of noise, especially if a remote reference is used in the survey. These parameters are used mainly to evaluate data quality, and perhaps for 3-dimensional effects. From our reading of the Ceboruco report, it appears that the contractor has examined these data.

In most of his routine interpretations, Wannamaker checks the error bars on the TE and TM mode apparent resistivity plots to evaluate data quality and dimensionality. If there are quality or interpretation problems he would then examine the other parameters in more detail. He says that you could certainly compute tipper, skew and other parameters to use in verification of numerical modeling, but this is not generally done. He emphasizes that even if a conductive body is indicated, the main interpretation problem is to determine if the conductive body is a regionally altered volcanic unit, or is more specifically related to the presence of a geothermal system.

I think it would be beneficial for you to visit UURI and discuss MT interpretation in more detail with Dr. Wannamaker. Perhaps you could bring specific problem MT data or models to discuss. He will return to Salt Lake City in late January 1995, and would then need some time to address other problems. He suggests that the best time for discussions would be about March 1995.

As you know, several geothermal researchers are working with geothermal simulators for reservoir modeling, and have published results in the GRC Transactions (i.e. Elliot Yearsley, David Faulder, and G. Mike Shook). Two other researchers who have been working on combined conductive-convective heat transfer modeling without the full reservoir simulation are:

Dr. William D. Gosnold
Department of Geology and Geological Engineering
University of North Dakota
Box 8068, University Station
Grand Forks, North Dakota 58202
Tel. (701) 777-2631 FAX (701) 777-4838

Dr. Henry P. Heasler
Department of Geology and Geophysics
University of Wyoming
P.O. Box 3006
Laramie, Wyoming 82071-3006
Tel. (307) 766-4200 FAX (307) 766-2737

Gerado Garcia E. may wish to contact these researchers to determine the status of their heat flow studies.

Sincerely,

Howard Ross

Howard P. Ross
Section Head/Applied Geophysics

```
*************** -COMM.JOURNAL- ******************** DATE NOV-22-1994 ***** TIME 11:52 **** P.1

    MODE = TRANSMISSION                           START=NOV-22 11:42      END=NOV-22 11:52

   NO.      COM     SPEED/NTWK  STATION NAME/        PAGES     PRG.NO.    PROGRAM NAME
                                TELEPHONE NO.

  001        OK     ☎           90115243144735       003

                                                        -U OF U RESEARCH          -

***************************************( FAX-310  V2.12)* -        801 584 4453- ************
```

HR

REMOTE SENSING OVERHEADS

1. Title slide and introduction

2. Landsat TM Bands

Band	Microns	Range	Presentation
7	2.1-2.4	near IR	red
6	-	--	--
5	1.5-1.8	near IR	--
4	0.8-0.95	far red	green
3	0.65-0.7	red	--
2	0.55-0.63	yellow	--
1	0.45-0.53	green	blue

Pixel size: 25 x 25 m

1. Raw Thematic Mapper (TM) image subset of Ceboruco Volcano area. Bands 7, 4, and 1 are represented by red, green, and blue respectively, on the image. This is low resolution TM data (25 x 25 m). Image field is 28 x 35 km, = 980 sq km. Note San Pedro Dome. Black area in NW is a lake. Green is dense vegetation (near IR). Casual inspection shows NW-SE, and SW-NE structures.

2. Vegetation and water masked TM data.Both vegetation and water interfere in the generation of the 5/7 band ratio as they wll appear as argillic or water-bearing minerals. The bands are the same as in 1. above. Black areas are water and/or dense vegetation and are completely masked out. Note drainages; N side of domes, hills.

3. Color ratio composite (CRC) consisting of the bands 5/7, 3/1, and 5/4 ratios assigned to red, green and blue. Bright reds indicate OH or water bearing minerals, and/or calcite. Bright greens indicate ferric iron-bearing rocks and minerals. Bright blues indicate ferrous iron and/or limonite-bearing rocks and minerals. Whites represent a mix of all three components. Yellows represent a mix of 5/7 and 3/1. Magenta represents a mix of 5/7 and 5/4. Whites, yellows, and sometimes magentas and reds are the best indicators for hydrothermal alteration.

These patterns represent surface soils and lithology, and alteration and weathering effects. Field checking is required to differentiate alteration from other effects.

4. Feature-oriented principal component selection (FPCS) image. This image was produced by selective band input into principal component analysis to achieve the desired results. Eigenvectors act as a guide to what each component represents. For instance a high negative eigenvector for band 7 and a high positive eigenvetor for band 5 would produce results similar to the bands 5/7 ratio. These data are used to verify the CRC image.

Explanation. Here we have selected (searched for) the bands expected to be present for alteration (key eigenvectors). We have highlighted the key ones. (statistical processes). Image is compared to previous one to verify the ratio selection, etc.

red 7= 2,1-2.4μ near IR
green 4= 0,8-0.95μ beyond red
blue 1=0,45-.53μ green

Remote Sensing Overheads

San Pedro dome -

1. Raw Thematic Mapper (TM) image subset of Ceboruco Volcano area. Bands 7, 4, and 1 are represented by red, green, and blue, respectively, on the image. 28 km NS - 35 Km EW ≃ 980 Km²

Some suggestion of NW-SE, SW-NE structure

2. Vegetation and water masked TM data. Both vegetation and water interfere in the generation of the 5/7 band ratio as they will appear as argillic or water bearing minerals. The bands are the same as in 1. above. note drainages; more H_2O on N side hills;

7 = red
5 = green
1 = blue

3. Color ratio composite (CRC) consisting of the bands 5/7, 3/1, and 5/4 ratios assigned to red, green and blue. Bright reds indicate OH or water bearing minerals, and/or calcite. Bright greens indicate ferric iron bearing rocks and minerals. Bright blues indicate ferrous iron and/or limonite bearing rocks and minerals. Whites represent a mix of all three components. Yellows represents mix of 5/7 and 3/1. Magenta represents a mix of 5/7 and 5/4. Whites, yellows, and sometimes magentas and reds are the best indicators for hydrothermal alteration.

5/7 → red
3/1 → green
5/4 → blue

4. Feature oriented principal component selection (FPCS) image. This image was produced by selective band input into principal component analysis to achieve the desired results. Eigenvectors act as a guide as to what each component represents. For instance a high negative eigenvector for band 7 and a high positive eigenvector for band 5 would produce results similar to the bands 5/7 ratio. This data is used to verify the CRC image.

high spatial resolution
bands with expected results for alteration; key eigenvector
highlighted key ones - then statistics.

MT ?s. 11/17/94

with Phil

- MT Tipper, Phase, Skew, Coherency, and other data could be requested from MT contractor - probably 1-2 disketts in ASCII format.

- Coherency, skew less often used now, esp. if a remote reference is used in the survey. Was used mainly to evaluate data quality.

- PEW mainly (in routine effort) checks error bars on ρ_a plots to evaluate data quality, 2-D or 3-D.

- Could certainly compute Tipper, skew etc and use in verific. of modeling, not generally done (even old UURI programs do it). Even if modeling shows conductive body, is it tuff or geothermal zone?

same old problem

Wannamaker's schedule

- Return to SLC late January
- Mtgs, catch up in Feb.
- March earliest (& best) for interaction before beginning '95 field program w. B & R

Tipper Phase
Tipper Magnitude
Tipper strike
E multiple coherency
HZ multiple coherency
Impedance skew

DOE - CFE @ Colonial Hotel (11/15)

①

New Results -

- Good temperatures in current well @ 1500
@ Ceboruco
- Achieved first flow @ new well @ Tres Virgne
- Drilling @ 6 new areas
- 100 new MWe @ Azufres.
- Looking at all renewables
- Goal of 1000 MW in Wind Power

Lunch @ 12:30 pm ; finish @ 5:30 - 6:00

Dinner @ 6:30 pm.

Discussions with P.I.'s tomorrow - but ope

Presentation of Final Papers by last week
in April 1995 ; in San Diego -
Summary with final papers in a volume
by early April / Conflict with World
Congress - latest will be 3rd week of April

Meeting 25, 26 April following Easter ②
Tu, Wed Meeting with completed reports

Present a paper w. Camera-ready copy

TOPICS 1995

① Geology and Hydrogeology
② Geophysics
③ Reservoir Eng.
④ Reinjection (exploration)
⑤ Subsidence and Induced Seismicity

Lobby @ 6:30 pm

* Conductive & Convective
Thermal modeling

Files ASCII

No. MT TE TM

C-89

25 freq.

no Tipper ✓
skew
no phase
multi. ?

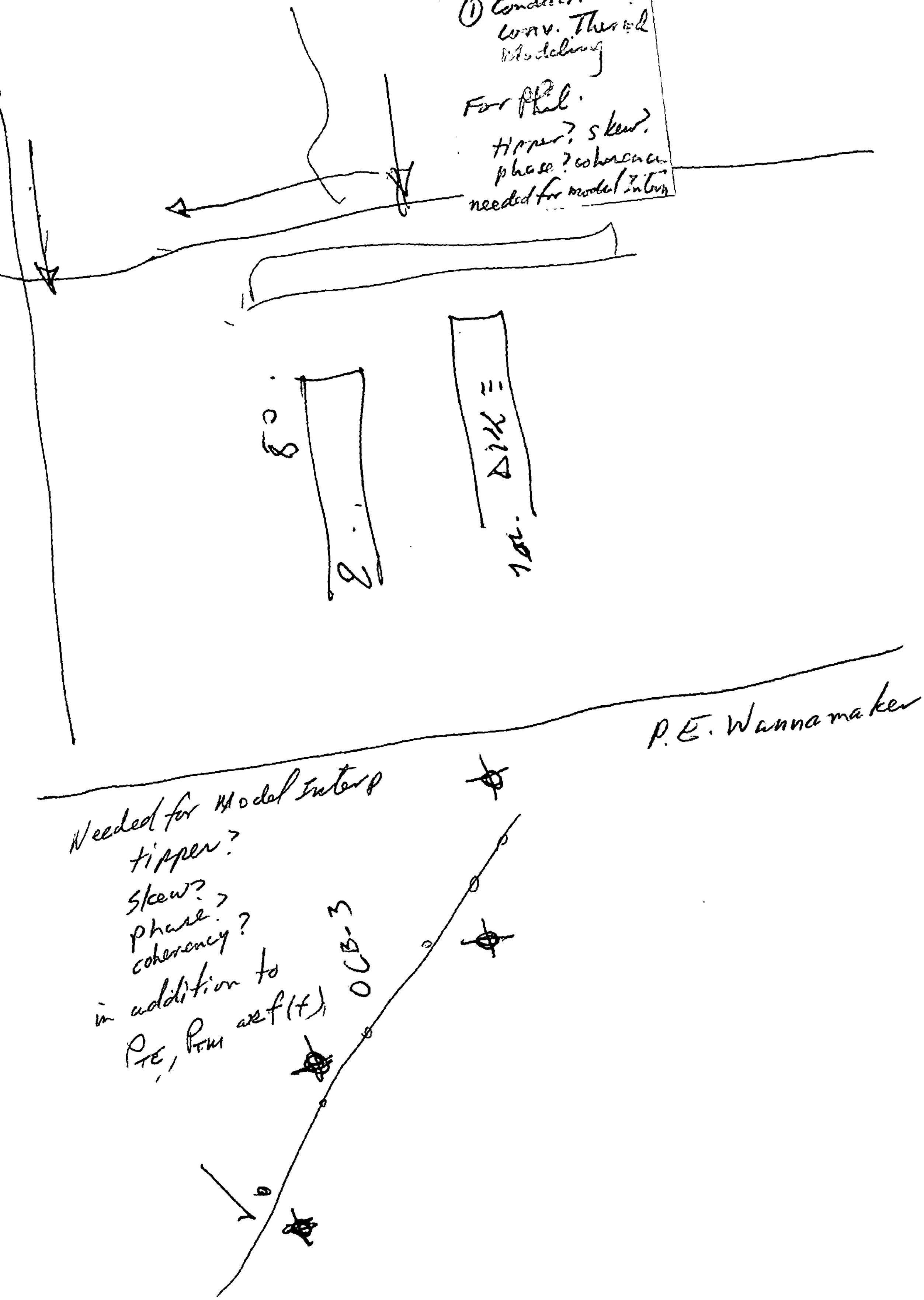
General File

Hi 25 freq. L

11/15/94
@ CFE-Mexicali

For
Gerado Garcia
① Conduct. --
Conv. Thermal
Modeling

For Phil:
tipper? skew?
phase? coherency
needed for model Interp



P.E. Wannamaker

Needed for Model Interp
tipper?
skew?
phase?
coherency?
in addition to
ρ_{TE}, ρ_{TM} as f(f)

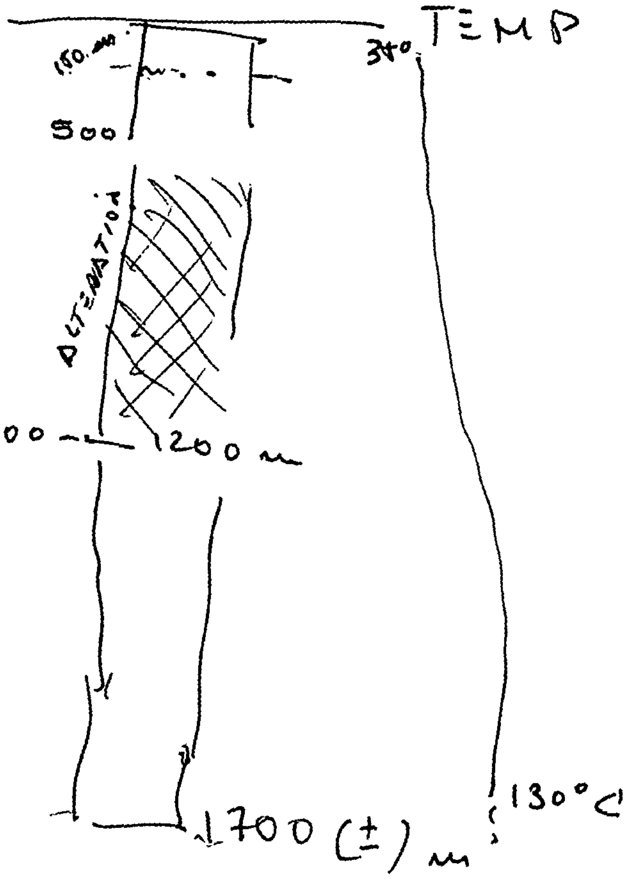
NORTH CEBORUCO — TEQUEPEXPAN

1 WELL 200 m <25°
RIOLITAS ~ ALTERED

AMADO NERVO

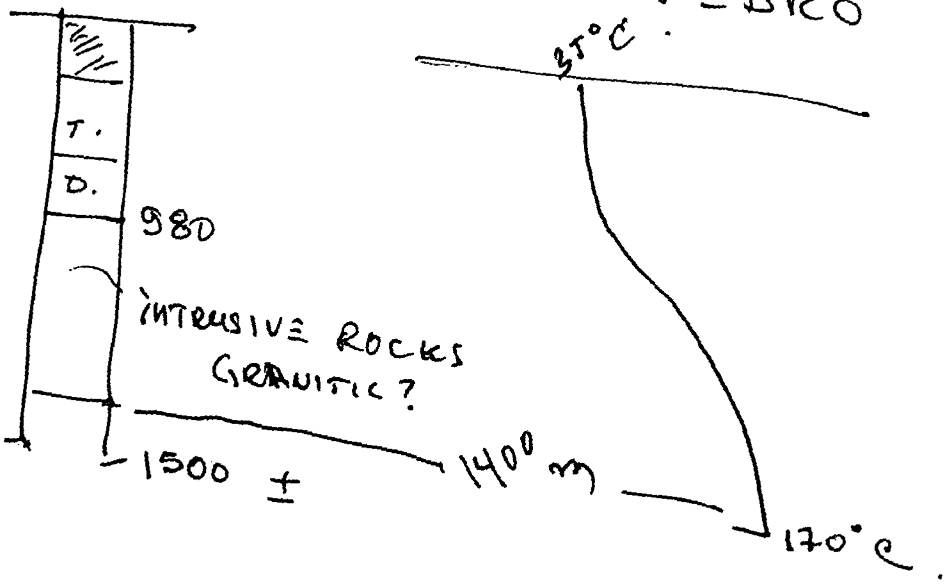
CB-2

Hot springs. 35° C



CB-3

WEST DOMO SAN PEDRO

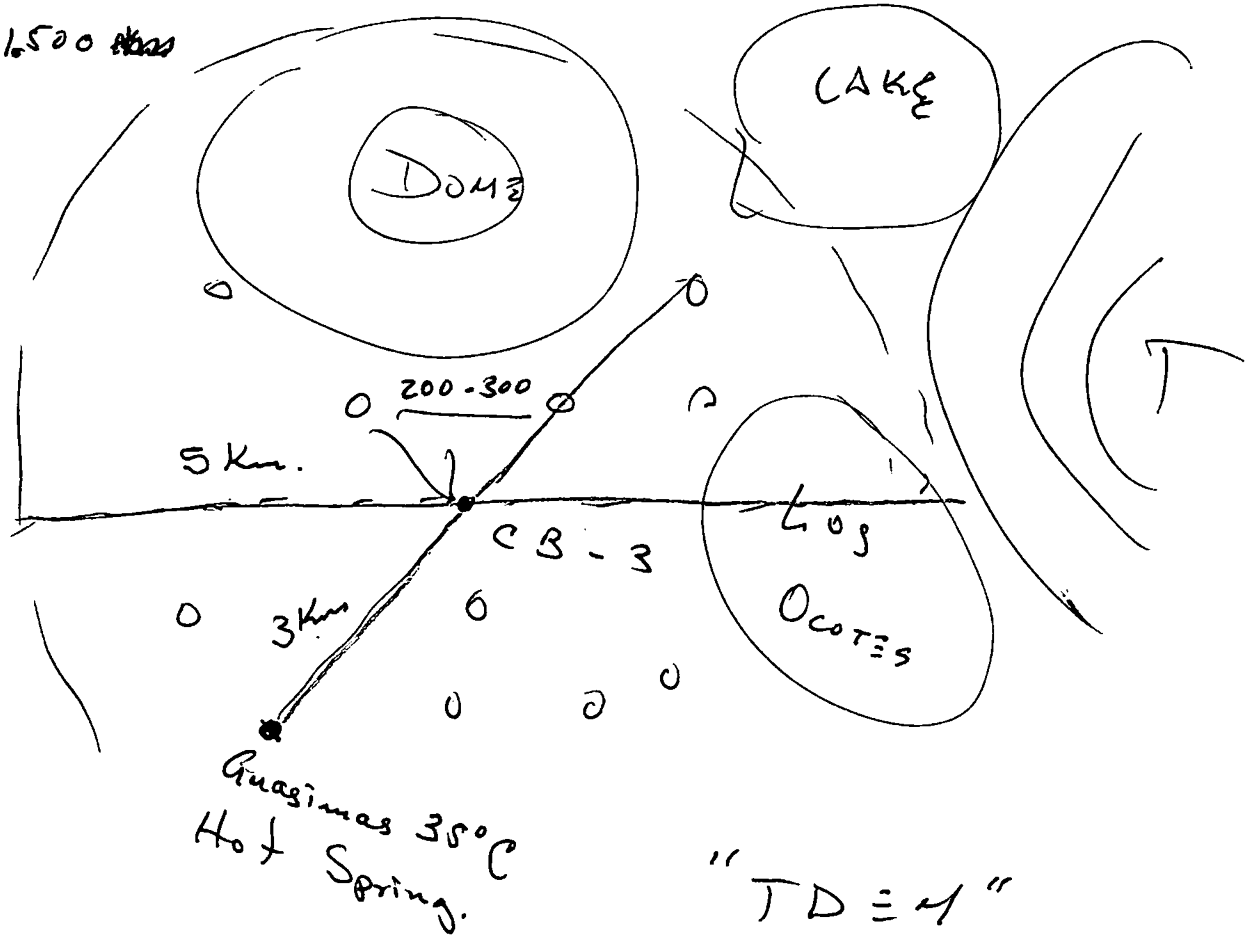


30, 7, 7.36 Hz.

-55 TDEM.

800 - 1400 ± m.
200 - 400 m

1000 - 1500

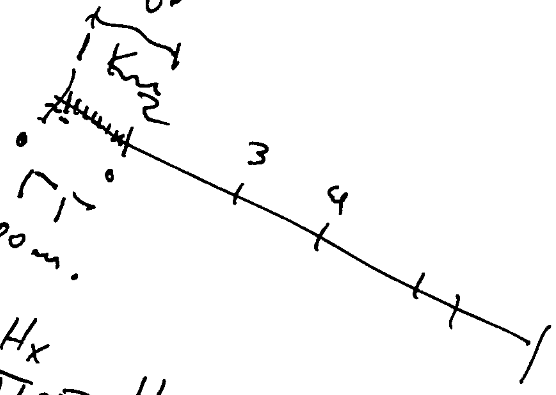


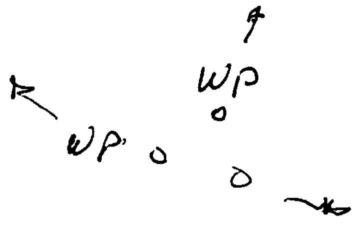
"TDEM"

GEODATOS "Chile"

-1000 m
-2000 m

PEC ≠ EMAP. Hx Hy Hz





GEOPHYSICAL STUDIES
CEBORUCO GEOTHERMAL RECONNAISSANCE AREA

Phillip E. Wannamaker, UURI J. F. Arellano G., CFE
Howard P. Ross, UURI

Background

- Ceboruco area, western Neovolcanic Belt, identified by CFE as a promising geothermal area from geologic, geochemical, geophysical studies
- Extensive geophysical program, 1983-1992; ending with 90 MT stations
- CB-1 drilled to 2,800 m; T max. = 112 C

Program for 1994

- Review and critique MT data and interpretation (UURI)
- Complete new MT modeling/interpretation, as needed (UURI and CFE)
- Review supporting geologic and geophysical data (UURI)
- Review/~~critique~~ Ceboruco exploration strategy (UURI)

2

CEBORUCO - GEOPHYSICAL STUDIES

Data Reviewed

- Regional Geology, Tepic-Zacoalco Graben, Nayarit
- El Ceboruco Geothermal Project, State of Exploration
- Gravity Studies, and Bouguer Anomaly Map
- Regional Aeromagnetic Studies
- Integration of Electrical Resistivity Studies
- Magnetotelluric Data, and Interpretations
- CB-1: Lithologic Column and Temperature Results

Problems Encountered

- ✓P. Wannamaker, H. Ross, GRC — Schedule
- Report review - Spanish to English
- Correspondence and discussion
- GEOTOOLS
- Location of CB-1 uncertain to UURI
- Geoevaluaciones MT Plates 1-14 missing
- Ceboruco - S24 missing

VIEWGRAPHS - TOPICS

1 Introduction- program, problems, data
2 Location map
3 Exploration strategy
4 Exploration Strategy - U S Industry
5 Exploration Strategy - Ceboruco
6 Results: magnetics, gravity, electrical resistivity
7 Comments and Questions - Ceboruco
8 MT Interpretation: Geoevaluacions vs CFE
9 MT Interpretation: Data density for MT stations - map
10-X: MT Interpretation: Phil

no viewgraph

③

EXPLORATION STRATEGY - GEOTHERMAL RESOURCES

Purpose

* Systematically apply a selected mix of exploration techniques tailored to the geologic environment and the expected geothermal resource type
* Staged exploration to minimize risk of failure
* Staged exploration to minimize cost

U S Industry Perspective

* Profit oriented - capital is at risk
* Competition for best prospects and resources
* Risk of missed resource with improper exploration
* Reduced profit with high front-end (exploration) costs
* Cost-effective exploration minimizes costs of geophysics; Cost-effective geophysics minimizes costs of drilling
* Largest costs are due to deep drilling

UURI Exploration Strategy - Developed with Industry

* EXPLORATION STRATEGY FOR HIGH-TEMPERATURE HYDROTHERMAL SYSTEMS IN BASIN AND RANGE PROVINCE - S.H. Ward, H.P. Ross, D.L. Nielson: AAPG Bulletin, 1981

* REGIONAL EXPLORATION FOR CONVECTIVE-HYDROTHERMAL RESOURCES - P.M. Wright, D.L. Nielson, H.P. Ross, J.N Moore, M.C. Adams, S.H. Ward: Geothermal Science & Technology, 1989

* STATE-OF-THE-ART GEOPHYSICAL EXPLORATION FOR GEOTHERMAL RESOURCES - P.M. Wright, S.H. Ward, H.P. Ross, R.C. West: Geophysics, 1985

---

④

CEBORUCO EXPLORATION RESULTS

REGIONAL GEOLOGY (9,000 sq km) >
GEOLOGIC MAPPING AND HYDROTHERMAL ALTERATION (3,500 sq km) >
DETAILED GEOLOGY AND HYDROGEOLOGY (1225 sq km) >
TEPIC-ZACOALCO GRABEN >
SAN PEDRO DOME - CEBORUCO VOLCANO AREA
CEBORUCO DRILL TEST - CB-1

(5)

GEOPHYSICAL SUMMARY

AEROMAGNETICS

- * Regional data, 6,000 sq km
- * Extensive processing, analytical operations
- * Interpretation confirms NW-SE, NE-SW trends proposed by photogeologic interpretation
- * Zones of low magnetization correspond to hydrothermal alteration
- * 2-D Model of magnetic basement at 800 - 1200 m
- * Indicates a zone of granitic basement

REGIONAL GRAVITY STUDIES

- * 450 sq km; 120 stations at 1 km spacing
- * To assist in structural interpretation and morphology of "basement"
- * Includes zones of interest from electrical resistivity (VES) and magnetotelluric (MT) data
- * Bouguer Gravity Anomaly map defines 5 NW-SE lineaments, and 2 NE-SW trends
- * Several gravity minima, including: Amado Nervo; Tetitlan; San Pedro Dome; Ahuacatlan; NE of Chapalilla; SW of Ceboruco volcano (CB-1 site)
- * Gravity believed to reflect the morphology of granitic basement
- * Dense andesites (2.7 g/cm3) below 2000 m in CB-1
- * Accuracy of Bouguer Gravity map: a) elevation (0.23 mGal/m); terrain corr; contouring.

(6)

ELECTRICAL RESISTIVITY STUDIES

- * Vertical Electrical Soundings (VES) - Schlumberger AB/2 = 500 m to AB/2 = 3000 m
- * Ceboruco-San Pedro Dome-Bartolinas area: 1250 sq km 1984-85, 78 stations; 1990-91, 107 stations; = 177 sta.
- * Broad low-resistivity zone (1-10 ohm-m) between San Pedro Dome and Ceboruco volcano (generally low topography)
- * High resistivity areas include most volcanoes, domes
- * Identified 11 sites with major electrical conductors for drill hole locations, including: Ceboruco; Las Cuevas; Santa Isabel; Casa Blanca; Amado Nervo; Bartolinas

TEMPERATURE GRADIENT RESULTS

- * 5 Gradient Holes in central area of 90 sq km

Drill Hole	Depth (m)	Ts	Tbh	Tg (C/km)
GC-1 (Santa Isabel)	150	---	43	+10
GC-2 (San Pedro)	110	34	28	-60
GC-3 (Bartolinas)	180	49	42	+96-130
GC-4 (Las Cuevas)	180	---	48	+12
GC-5 (Amado Nervo)	190	42	37	+37

* GC-? (SW Ceboruco) ~~CB-1~~ ← 400 --- 46 +21

* CB-1 (SW Ceboruco) ←2800 --- 112 +39

(1)

PRELIMINARY CONCLUSIONS

* Area of geothermal resource potential reduced to 30 x 20 km, or about 600 sq km.

* Regional low resistivity zones complicate electrical resistivity (VES) and MT interpretations

* Geoevaluaciones S.A. de C.V., MT contractor, identified 3 areas where TM, TE apparent resistivity plots suggested conductive zones to depth; ~~thus~~ possible good targets:
  Northern Ceboruco; Amado Nervo; San Pedro

* CFE identified the SW Ceboruco area as a favorable low-resistivity zone; discounted by Geoevaluaciones

* MT data density was not sufficient to select a 2.8 km drill hole; Geoevaluaciones recommended 30-40 new sites per area Sens.

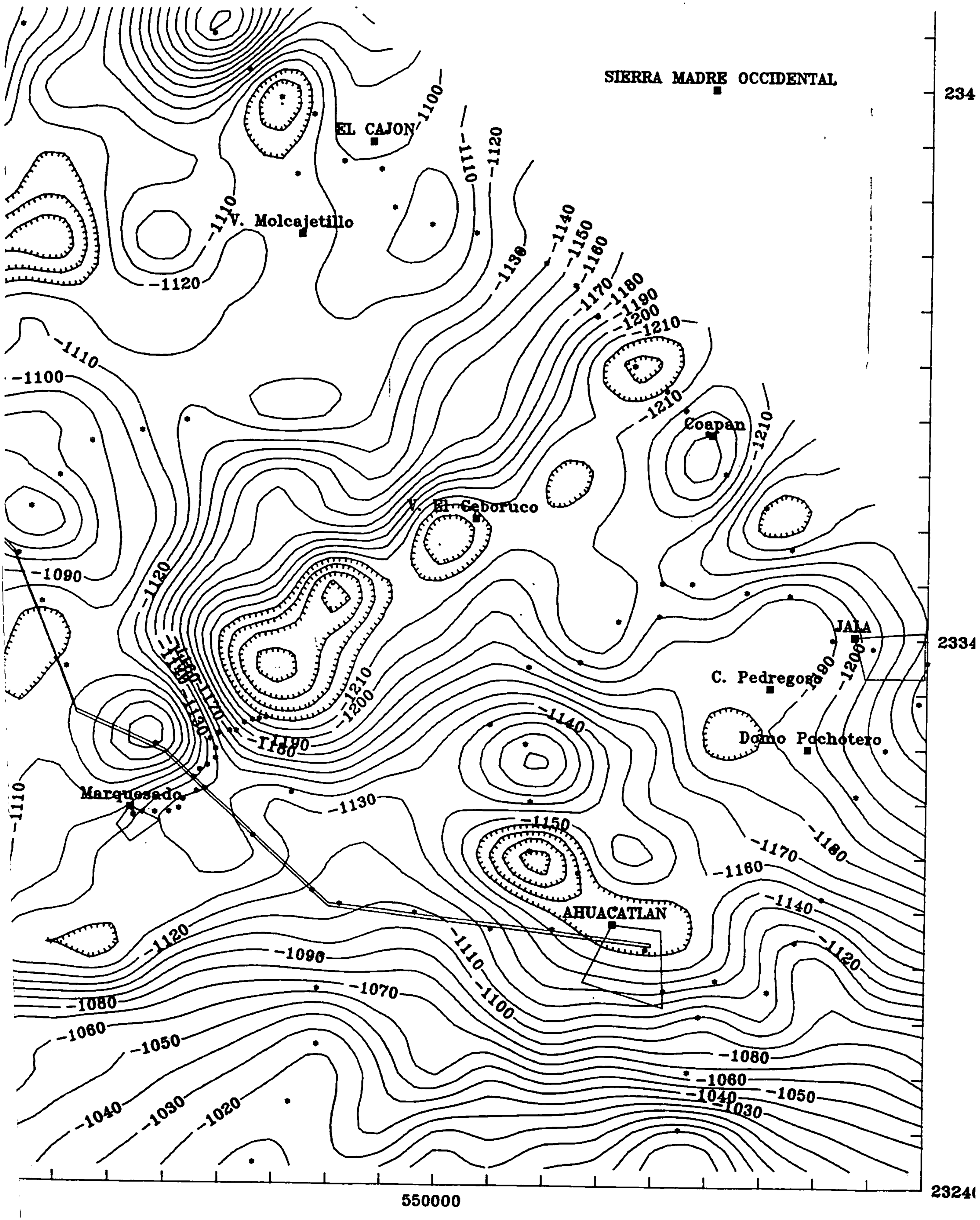
* 5 shallow temperature gradient holes, in central 90 sq km area Temperatures and gradients not very encouraging.

* Temperature gradient hole at CB-1, to 400 m, not very encouraging for high temperatures at moderate depth.

* CB-1 was sited on several types of evidence:
  geologic-tectonic model; volcanic setting;
  MT low-resistivity; Bouguer gravity minimum

* Additional MT stations (20-30) and several intermediate-depth (200-400 m) temperature gradient holes are recommended before siting deep (>1000 m) exploratory wells Sens.

* Geothermal system more restricted than first thought (CFE-GRC paper) or located elsewhere near Ceboruco volcano.


SIERRA MADRE OCCIDENTAL
EL CAJON
V. Molcajetillo
V. El Ceboruco
Coapan
JALA
C. Pedregoso
Domo Pochotero
Marquesado
AHUACATLAN
-1100
-1110
-1120
-1130
-1140
-1150
-1160
-1170
-1180
-1190
-1200
-1210
-1090
-1080
-1070
-1060
-1050
-1040
-1030
-1020
234
2334
2324
550000

DOE-CFE Geothermal Agreement

GEOPHYSICAL STUDIES
CEBORUCO GEOTHERMAL RECONNAISSANCE AREA

Philip E. Wannamaker and Howard P. Ross - UURI
J. F. Arellano G. - CFE

PROGRESS REPORT for 1994

Introduction

This project was suggested by CFE scientists at the second technical meeting, January 1994. The Ceboruco area, within the western Neovolcanic Belt, was identified as a promising geothermal area for additional geophysical studies during the 1989-1994 agreement. CFE completed extensive gravity, aeromagnetic, electrical resistivity and magnetotelluric (MT) studies in the greater Ceboruco reconnaissance area (approximately 1200 sq km) but UURI was unable to participate due to lack of project funding. Initial drilling results, including the 2800 m deep CB-1 were disappointing. Since the drill hole was sited in part on geophysical (MT, gravity) results, CFE requested a review of contractor geophsical data and interpretations. UURI has had a continuing interest in the geothermal exploration strategy and proposed a general review of the geophysical exploration effort.

Planned Scope of Project for 1994

The scope of the project for 1994 was to:

1. Review the Ceboruco exploration strategy.
2. Review supporting geologic and geophysical data.
3. Review and critique MT data and interpretation.
4. Complete new MT modeling and interpretation, as needed.

Results to Date

CFE scientists transmitted an extensive geologic and geophysical database to UURI. The geologic studies provided necessary background for the understanding and interpretation of the geophysical data, and for an understanding of the exploration strategy. UURI scientists reviewed the various reports and data.

Dr. Wannamaker completed a detailed review of the MT reports and data completed by GeoEvaluaciones. He found the treatment and evaluation of the data to be competent, and the interpretation generally valid. The occurrence of conductive volcanic horizons has been noted at Long Valley, California, and in the Cascades in the Pacific northwest, and these occurrences have presented severe interpretation and exploration problems in these areas also. Dr. Wannamaker has identified some additional concerns with MT data interpretations in these environments. The

MT contractor computed appropriate two-dimensional (2-D) models, and new numerical modeling was not deemed necessary. UURI was unable to obtain the necessary software in time to use the GEOTOOLS formated MT data submitted by CFE.

A second interpretation of the MT data was completed by CFE geophysicists. This interpretation called attention to several MT stations SW of Ceboruco volcano which suggested a larger conductivity-thickness body at depth. These stations had not been identified by GeoEvaluaciones as a promising target area because they did not exhibit a response typical of conductive bodies going to depth, and were believed to be part of the region-wide conductive horizon. Decreases in apparent resistivity observed for periods longer than 1 to 10 seconds are due to the regional, mid-crustal state, with some short scale data variations caused by minor static shifts, or data noise.

Dr. Ross reviewed the aeromagnetic and gravity data, and noted that extensive state-of-the-art processing had been applied to the aeromagnetic data. A final, geometric interpretion of magnetic bodies and geologic structures was not noted, however.

The gravity survey is described as a reconnaissance level survey which probably was restricted to existing roads and trails. The locations of gravity stations were determined by vehicle odometer (+/- 100 m), and station elevations were estimated from contour maps (estimated to be +/-10 m). It does not appear that terrain corrections were applied to the data, and these could be quite significant (1-3 mGal, 10-30 g.u.) near Ceboruco volcano. Elevation errors could result in errors of as much as 2.2 mGals (22 g.u.). Another limitation of the Bouguer gravity map, especially in the area near CB-1, is the relatively low data density. Although the automated contour interpolation routine may provide the best estimate of gravity contours, it could lead to considerable error in areas of low data density, especially when using data which may be in error due to elevation errors and without terrain corrections. Thus the gravity map may be useful in projecting regional geologic features, but may be inappropriate for use in drill site selection.

Plans for 1995

1. Additional detailed MT interpretation could be undertaken if specific interpretation problems are identified by CFE geophysicists, such as evaluating proposed drill targets.

2. UURI suggests a detailed evaluation of the accuracy of the Bouguer gravity map for an area of approximately 100 sq km, including the large gravity low which extends southwest from Ceboruco volcano. Gravity data should be obtained at 25 to 50 stations, well distributed between the existing stations. Positions and elevations should be accurately determined for these and nearby existing stations (GPS control?) and full terrain corrections should be applied.

Chi's Tours
TRAVEL AGENCY, INC.
[illegible] South Main Street, Suite 201 Salt Lake City, Utah 84111
Phone (801) 322-1205 Telex Number 5105010035 CHIS TOURS

MOORE/JOE

E S L D
391 Chipeta Way Suite A
Salt Lake City, Utah 84108
Attention: "Carolyn"

CUSTOMER'S COPY

E07SK NOV 10 1994 6893TW INVOICE- 18090

14 NOV 94 - MONDAY
DELTA 1787 COACH CLASS CONFIRMED
LV: SALT LAKE CTY 427P AR: LOS ANGELES 515P
SEAT-32D

14 NOV 94
DL CODESHARE 5446 COACH CLASS CONFIRMED
OPERATED BY-SKY WEST AIRLINES
LV: LOS ANGELES 605P AR: EL CENTRO/IMP 705P
SEAT- 4A

16 NOV 94 - WEDNESDAY
DL CODESHARE 5422 COACH CLASS CONFIRMED
OPERATED BY-SKY WEST AIRLINES
LV: EL CENTRO/IMP 920A AR: LOS ANGELES 1015A
SEAT- 3A

16 NOV 94
DELTA 968 COACH CLASS CONFIRMED
LV: LOS ANGELES 1225P AR: SALT LAKE CTY 307P
SEAT-27D
SNACK

TICKET NUMBER/S:

MOORE/JOE	1485145879	CHECK	432.00

AIR TRANSPORTATION	387.28	TAX	44.72	TTL	432.00
		SUB TOTAL			432.00
		AMOUNT DUE			432.00

r than the country
erns and in most
nage to baggage.
of Liability" and

eas territories and
ations, tariffs and
nce and made part

pecific terms and
ket set or may be

tions of Contract",
, and "Notice of
or services. If not,

NOT TRANSFERABLE

PASSENGER RECEIPT

ARC

ISSUED BY DELTA AIR LINES
AGENT CODE A46594785
NAME OF PASSENGER MOORE/JOE
NAME OF ISSUING AGENT CHIS TOURS
PLACE OF ISSUE / DATE OF ISSUE SALT LAKE CITY UTUS10NOV94
NAME OF PASSENGER MOORE/JOE 68Q3TW/UA MULTI 65880/
NOT VALID FOR THIS IS YOUR RECEIPT
TRANSPORTATION
ISSUING AGENT ID E078K

SLCLAXDL1787K 14NOV
FROM LAXIPLDL5446Q 14NOV
IPLLAXDL5422Q 16NOV
TO LAXSLCDL 968K 16NOV

ENDORSEMENTS/RESTRICTIONS

FP CHECK FC 14NOV SLC DL LAX 99.09KSLC DL IPL
94.55Q DL LAX 94.55Q DL SLC 99.09KSLC USD387.28 END
XFLAX3LAX3

FARE USD387.28
TAX US38.72
TAX XF6.00
TOTAL USD432.00

EQUIV. FARE PD.
STOCK CONTROL NO. 46986295300
DOCUMENT NUMBER 0 006 1485145879 3

DO NOT MARK OR WRITE IN THE WHITE AREA ABOVE

NOT VALID FOR TRAVEL
0 006 1485145879 3

CHIS TOURS CLIENT: MOORE/JOE
115 SO MAIN SUITE 201 PAGE:01
SALT LAKE CITY UT 801-322-1205 INVOICE: 18090

14 NOV DELTA FLIGHT: 1787 CLASS: K SEAT: 32D
MO SALT LAKE CTY DEPART: 427P
LOS ANGELES ARRIVE: 515P

14 NOV DL CODESHARE FLIGHT: 5446 CLASS: Q SEAT: 4A
MO LOS ANGELES DEPART: 605P VIA: SKY WEST AIRLINES
EL CENTRO/IMP ARRIVE: 705P

16 NOV DL CODESHARE FLIGHT: 5422 CLASS: Q SEAT: 3A
WE EL CENTRO/IMP DEPART: 920A VIA: SKY WEST AIRLINES
LOS ANGELES ARRIVE: 1015A

CLIENT: MOORE/JOE PAGE:02

16 NOV DELTA FLIGHT: 968 CLASS: K SEAT: 27D
WE LOS ANGELES DEPART: 1225P
SALT LAKE CTY ARRIVE: 307P SNACK

HOTEL RESERVATIONS - Nov. 14 & 15, 1994
Joe Moore

Ramada Inn
1455 Ocotillo Dr.
El Centro, CA 92243

(619) 352-5152

$48.00 + 10% tax per night

Confirmation # 630953

HR

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-524-3422

September 6, 1994

Ing. Saul Venegas S. Salgado
Jefe del Departamento de Exploracion
Gerencia de Proyectos Geotermoelectricos
Comision Federal de Electricidad
Morelia Michoacan
Mexico

Dear Sr. Venegas:

Dr. Wannamaker's comments describing his review of the magnetotelluric (MT) data for the Ceboruco-San Pedro geothermal area are transmitted herewith. Some additional comments follow.

A favorable time for a CFE geophysicist to visit UURI and discuss the MT interpretation would be October 5-7, immediately after the GRC meeting in Salt Lake City. Dr. Wannamaker is preparing for an extended field survey out of the country and his time in Salt Lake City will be limited. Perhaps a few numerical models could be computed at this time, if desired.

We do not have GEOTOOLS running on our computer system at the present time. If the CFE geophysicist intends to process or model any MT data it would be necessary to bring the MT data on disk as an ASCII file.

We would like to know the exact (map) location of the deep drill hole in order to evaluate the drill results in terms of nearby MT soundings and gravity and magnetic expressions.

Dr. Wannamaker has selected two short technical papers (Pellerin et al., 1993, and Simmons and Browne, 1990) which relate to low-resistivity zones due to altered volcanics which may relate to the Ceboruco-San Pedro case. We will send these to you under separate cover.

Sincerely,

Howard Ross

Howard P. Ross
Section Head/Applied Geophysics

cc: P.M.Wright
P.E.Wannamaker

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

September 7, 1994

Ing. Saul Venegas Salgado
Jefe del Departamento de Exploration
Gerencia de Proyectos Geotermoelectricos
Comision Federal de Electricidad
Morelia Michoacan
Mexico

Dear Sr. Venegas,

I have finally had an opportunity to examine the magnetotelluric (MT) data and interpretations from the Ceboruco-San Pedro geothermal area sent to our lab last May. Materials include a report on the state of the exploration in 1992 authored by yourself and Ing. Arellano, a lengthy interpretation dated November 1991 by Messrs. Copley and Orange of AOA, Inc., and an additional report dated April 1993 by Ing. Guzman. A lithologic log of deep well CB-1 was received also although we were not able to find a precise location for it.

The interpretation of Copley and Orange, summarized in the state-of-exploration report, is the most quantitative and detailed. Overall, I find it to be competent and credible. The response of most of the 93 soundings distributed over 1250 km^2 is dominated by the presence of a low resistivity layer at a depth of a few hundred meters typically. This was judged by Copley and Orange to represent a stratigraphic horizon of altered volcanics and derived sediments. I agree with that conclusion and note that rhyolitic tuffs especially have a tendency to be altered and conductive. Two examples of this with which we are familiar include the northwest U.S. Cascades (Wannamaker et al., 1989, J. Geophys. Res.) and Long Valley caldera (Wannamaker et al., 1991, Geophysics). Such horizons can be of economic geothermal interest <u>on a local basis</u>, such as in the latter example, but this usually must be established by means independent of MT. Generally, these conductive horizons are not of interest in exploring for geothermal energy.

Copley and Orange go on to identify three intermediate-scale areas of anomalous behavior which they suggest may have some geothermal significance. These are north of Ceboruco volcano, near Amado Nervo, and south of San Pedro volcano. The identification was based upon the so-called E-parallel (to local strike) or transverse electric (TE) mode of response showing a more pronounced apparent resistivity minimum at intermediate frequencies, while the E-perpendicular or transverse magnetic (TM) mode showed decreasing apparent resistivities towards the lowest frequencies. A simple 2-D model given by Copley and Orange reproduced the effect approximately using a conductive dike between shallow and deeper conductive layers, such as exist widely over the area. However, it was necessary to include a broadening base to the dike-like structure in order to reproduce the TM response at distances of several km from the dike. It also is not clear whether the narrowest and shallowest portions of the dike are required to reproduce the TE characteristics fundamentally. To me, it appears equally likely that buried 'topography' on the subsurface conductive stratum, subsequently covered by resistive lava flows, may be the geologic cause of this particular set of MT responses. It thus would be very risky to pursue these anomalous areas for geothermal resources without strong corroborating evidence.

In the western United States, widely-spaced MT soundings in a reconnaissance survey have not proved valuable in narrowing the search for geothermal resources. Value has been found in applying MT later in the exploration sequence for specific structural studies of areas identified through independent means, such as high-temperature alteration or spring geochemistry. In particular, MT appears to be the superior electrical method for attempting to resolve any deeper, more narrow and subtle, conduit zone for upwelling fluids beneath a cap of clay alteration. We enclose a short model study of such a structure for several electrical methods based upon a concept for geothermal systems of New Zealand.

I hope these comments will be of some value in understanding the magnetotelluric survey in question and the MT method in general. Please feel free to contact Dr. Ross or me directly with any other questions.

Yours sincerely,

Phil Wannamaker

Philip E. Wannamaker, Ph.D.

cc. H. P. Ross
    P. M. Wright

DEMONSTRATION OF A BIPHASE WELLHEAD POWER SYSTEM

Ing. Alejando Oropesa Quiroz

Comision Federal de Electricidad

Lance Hays

Biphase Energy Company

PROGRESS REPORT for 1994

Introduction

This project was proposed to demonstrate the application of Biphase turbine systems to improve the power output of the Cerro Prieto geothermal resource. The units proposed will be add-on units which generate power from the high-pressure well flow and which then deliver steam to the existing separators at the conditions required by the existing power plants. The Biphase units have isolation valves which enable the wells and plant to operate independently of the Biphase units.

A study previously conducted for CFE found that the best 40 wells could produce an additional 80 megawatts if Biphase turbines were added. The current agreement to demonstrate a single Biphase unit was signed in September of 1994.

Planned Scope of Project for 1994

The final engineering for the project is planned to be completed in 1994. Major equipment including the Biphase turbine, a back pressure steam turbine, the generator and electrical switchgear is planned to be ordered.

Results to Date

The following results have been achieved to date:

1. The well for the project was selected to be number 103.

2. The final Process and Instrumentation Diagram was prepared.

3. The final design of the Biphase turbine was completed. Power output of the Biphase wellhead system was calculated with the following results:

   Present equipment The well presently feeds a separator which operates at 110 psig. The well produces 81.5 T/h of steam. Steam from the separator feeds a condensing steam turbine. The steam rate is 11 T/MWh. The power produced by the flash steam flow from the well is 7410 kW.

   Equipment including the Biphase turbine A Biphase wellhead power system will be installed in parallel to the existing flash orifice. The Biphase wellhead system consists of a Biphase turbine, back pressure steam turbine, common generator and electrical switchgear. The Biphase turbine system accepts the two-phase flow from the well directly and expands it to the separator pressure, generating power. The steam flows through the separator to the existing central steam turbine generating additional power. The Biphase wellhead system generates 4150 kW. The steam leaving the Biphase system generates an additional 6610 kW in the existing central steam turbine.

   Obtained benefit with present equipment at Cerro Prieto I The present equipment produces 7410 kW from well 103. The addition of the Biphase wellhead power system results in a total of 4150 kW + 6610 kW = 10,760 kW. The power from the well is increased by 45%. The new steam rate, based on the flash steam flow is 7.6 T/MWh.

   Obtained benefit with improvements to present equipment If the present equipment at Cerro Prieto I is improved to a steam rate of 8 T/MWh the well would produce 10,190 kW. Addition of a Biphase wellhead power system will produce a total of 4150 kW + 9090 kW = 13,240 kW with the improved equipment. The power from the well is increased by 30% in this case. The new steam rate is 6.2 T/MWh.

Plans for 1995

The Biphase unit will be manufactured, installed and started in 1995. Startup should occur during the 4th quarter. The unit will be tested to determine if there are any deleterious effects on the operation of the well and steam system. Performance will be measured and compared to predictions. Reliability will be determined beginning in 1995 for a two year period of operation.

DOE - CFE GEOTHERMAL AGREEMENT

PROCESSES IN CERRO PRIETO GEOTHERMAL RESERVOIRS

A. H. Truesdell (consultant), M. J. Lippmann (LBL) and H. Gutiérrez Puente (CFE)

Progress Report for 1994

The Cerro Prieto I power plant is producing 180 MWe from mainly the deeper beta reservoir. The alpha reservoir is largely abandoned but some wells are still flowing. A few alpha wells show little change in temperature or chloride (e.g., M-42), but almost all show entry of cooler waters, probably descending along the L fault as described in earlier papers. Typical cool water entry is shown by well M-35. Even wells previously noted for boiling show dilution (M21A, M-31). The beta reservoir wells also show cool water entry (E-4) because this reservoir is also connected to cooler waters along its W margin, close to the CP-I wells.

Results to Date

The Cerro Prieto II and III power plants are fed exclusively by steam from the beta reservoir. The most interesting maps of this reservoir show the influence of the H fault on the properties of the reservoir. Movement along the fault has elevated the NW upthrown block (containing the CP-III part of the beta reservoir) by about 700 meters relative to the SE downthrown block as indicated by the depth to the top of the reservoir (Figure 1). Most wells of CP-II are in the downthrown block but some are in the hanging wall of the fault or in the upthrown block. There is a radical difference in the behavior of the beta reservoir in the NW and SE blocks.

In 1991 wells just NW of the fault produced high-enthalpy fluids with from 0.4 to >0.9 inlet vapor fraction (IVF) while almost all fluids from wells SE of the fault had <0.1 IVF (Figure 2). Fluids from the fault itself had intermediate values. Other quantities also differ between the upper and lower parts of the reservoir. 1991 reservoir chloride concentrations in the downthrown block were uniformly high (10,000 to 12,000 mg/kg except for two wells) and reservoir temperatures ranged between 300 and 320°C (Figures 3 and 4). In the upthrown block both temperatures and chloride vary widely. The maximum values (14,000 mg/kg Cl and >310°C) are similar to or slightly above those in the SE block, but several parts have low chloride and temperature (to 6000 mg/kg Cl and 280°C). These lower values are aligned along the upper fault intersection (wells M-193 and E-22) or in the zone of highest IVF values (wells M-107, M-125 and M-102). Some of these wells have normal temperatures with very high enthalpy and very low chloride due to high-temperature adiabatic steam condensation. The total discharge $\delta^{18}O$ map (Figure 5) shows fairly uniform gradient from -10.5 in the SW to -7.5 in the NE except for an elongate zone of fluids depleted in O-18 ($\delta^{18}O$ as low as -10.5). The lowest $\delta^{18}O$ fluids are also low in chloride and temperature (wells M-193, E-25 and M-107), but not all low temperature, low Cl fluids are low in $\delta^{18}O$ (well M-102) and vice-versa (well E-41).

The changes observed in the 1991 maps have continued in 1993. The most interesting difference is the apparent entry of isotopically heavier waters at the intersection of the fault H with the downthrown block in the CP-II area centered on well E-39 and affecting wells E-18 and M-73 (Figure 6). There is no evidence of higher chloride or higher enthalpy in these wells suggesting that isotopes and chloride are decoupled (enthalpy is buffered by heat conduction with rock) or that there are errors in the isotope analyses. The final interpretation should be confirmed by repeat analyses which are planned. The decrease in chloride, $\delta^{18}O$ and enthalpy along fault H observed in 1991 intensified in 1993.

The interpretation of these 1991 and 1993 observations on the Cerro Prieto beta reservoir is quite straightforward. The 700 m difference in elevation between the blocks must result in lower pressure in the upper block than in the lower one. Before exploitation, the fluid in the shallower block was probably at the boiling point, and that in the deeper block, significantly below boiling. In addition the upper block probably has closed boundaries related to the displacement of the H fault preventing flow from the SE. The NE part of this block is also relatively distant from the W edge of the reservoir, where lower $\delta^{18}O$, temperature and chloride suggest a leaky boundary. The downthrown block may connect to cooler aquifers to the S as suggested by lower $\delta^{18}O$ and chloride, and more importantly is at greater depth and has higher pressures. These factors have combined to produce general boiling (not just near wells) in the upthrown, NW block (high IVF), and little boiling in the SE block (IVF near 0). The highest IVF values are near the fault intersection, with lower values to the W and N probably as a result of pressure support from entry of cooler fluids at the reservoir margin.

The localized occurrence of cooler, less-saline, isotopically-depleted waters at the NE end of the fault H intersection and in a parallel zone to the NW is most probably due to the entry down the fault of cooler waters from above the beta reservoir. This is similar to the observed entry of cooler waters down the L fault into the shallow alpha reservoir, which started soon after the start of production. The entry of this cooler water will ultimately cool the reservoir, but will also recharge fluids and decrease the amount of boiling. The increase in reservoir liquid will maintain pressures, decrease gas and prevent the production of corrosive HCl.

At Cerro Prieto, extensive drilling, wellhead measurements, and collection and analysis of chemical and isotopic samples have allowed a good understanding of both near-well and reservoir processes over its 20 year history. The response to pressure drawdown in the shallow alpha reservoir was principally entry of cooler water, with boiling limited to the vicinity of certain wells. In the deeper beta reservoir drawdown has caused mainly general boiling in the upthrown NW block as a result of its lower pressure and relative isolation. In the downthrown block and at the W margin of the upthrown block much less boiling is observed, probably because cooler waters are being drawn in at reservoir margins. The *increasing entry of cooler water down fault H into the NE end of the upthrown block is* causing reduced boiling and may locally reduce the need for injection to maintain reservoir pressures.

Plans for 1995 (subject to DOE funding)

New data will be incorporated in the study as it becomes available. A suite of samples will be analysed for noble gas isotopes by Mack Kennedy at LBL. These samples from the alpha and beta reservoirs will include normal reservoir waters, inflowing cooler waters, and possible upwelling deeper water A short report will be presented at the World Geothermal Congress and a comprehensive report including 1994 data will be published in a refereed journal.

FIGURE CAPTIONS

Figure 1. The depth to the top of the Cerro Prieto beta reservoir based on drilling data from CFE (in meters) showing the location of the H-Fault at reservoir level (shaded).

Figure 2. Inlet vapor fraction (IVF) for 1991 Cerro Prieto production. IVF is a measure of excess enthalpy. See text for explanation.

Figure 3. Calculated 1991 chloride concentrations in the Cerro Prieto beta reservoir based on Na-K-Ca geothermometer temperatures (in mg/kg).

Figure 4. Calculated 1991 temperatures in the Cerro Prieto beta reservoir from the Na-K-Ca geothermometer (in degrees Celsius).

Figure 5. Calculated 1991 total discharge $\delta^{18}O$ values in permil SMOW for fluids from the Cerro Prieto beta reservoir.

Figure 6. Calculated 1993 total discharge $\delta^{18}O$ values in permil SMOW for fluids from the Cerro Prieto beta reservoir. The greater complexity compared to Figure 5 is due to substantially more data.

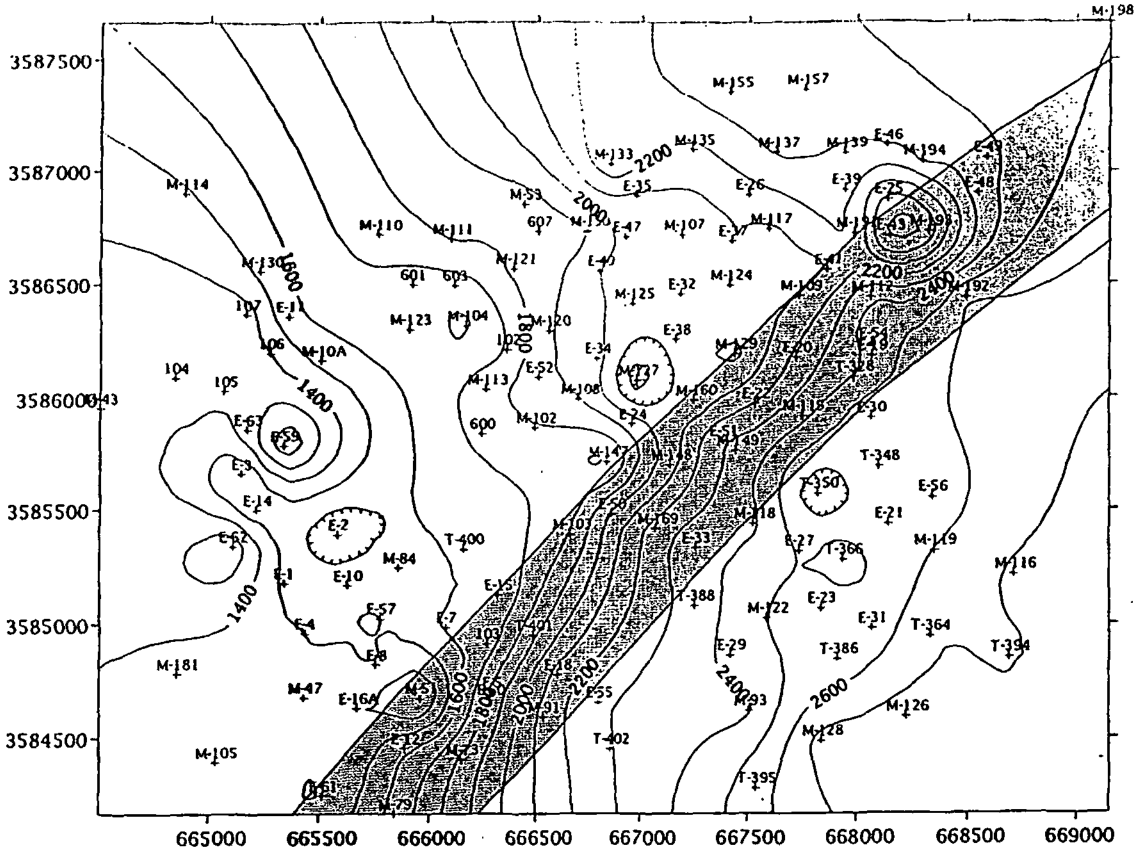


Figure 1.

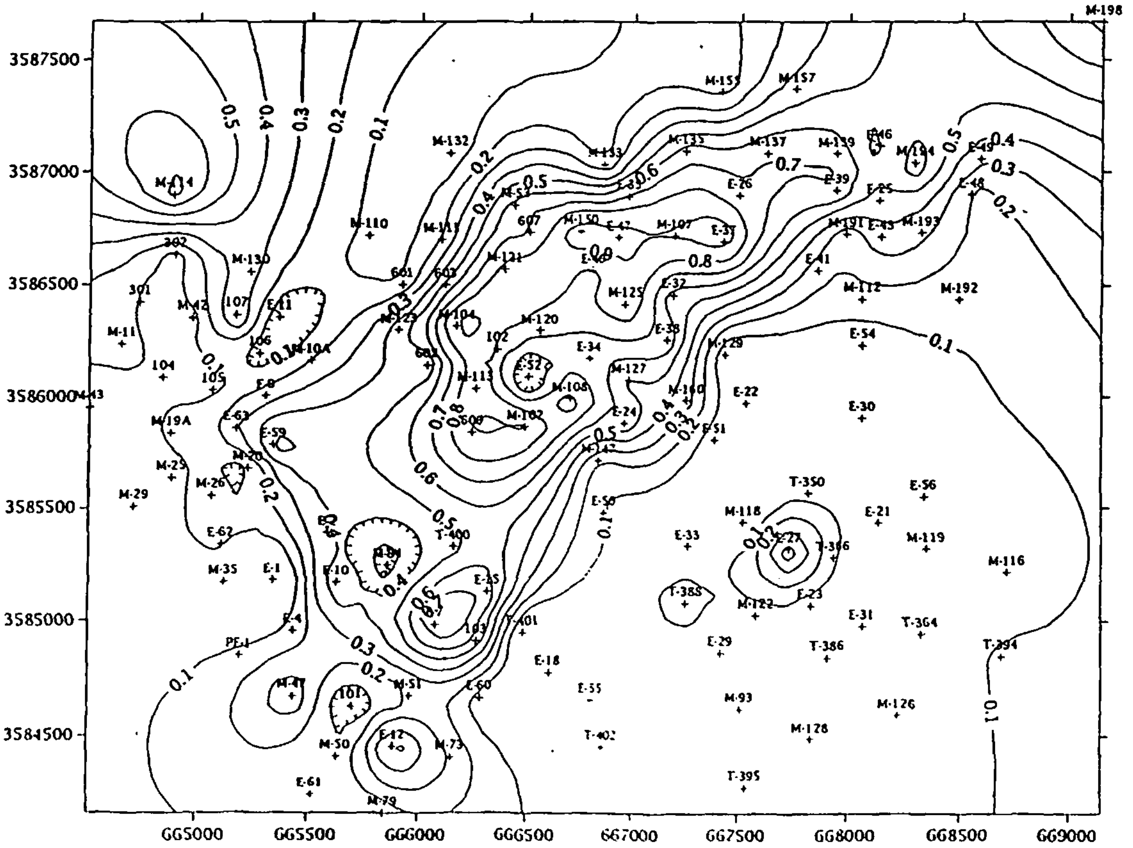


Figure 2.

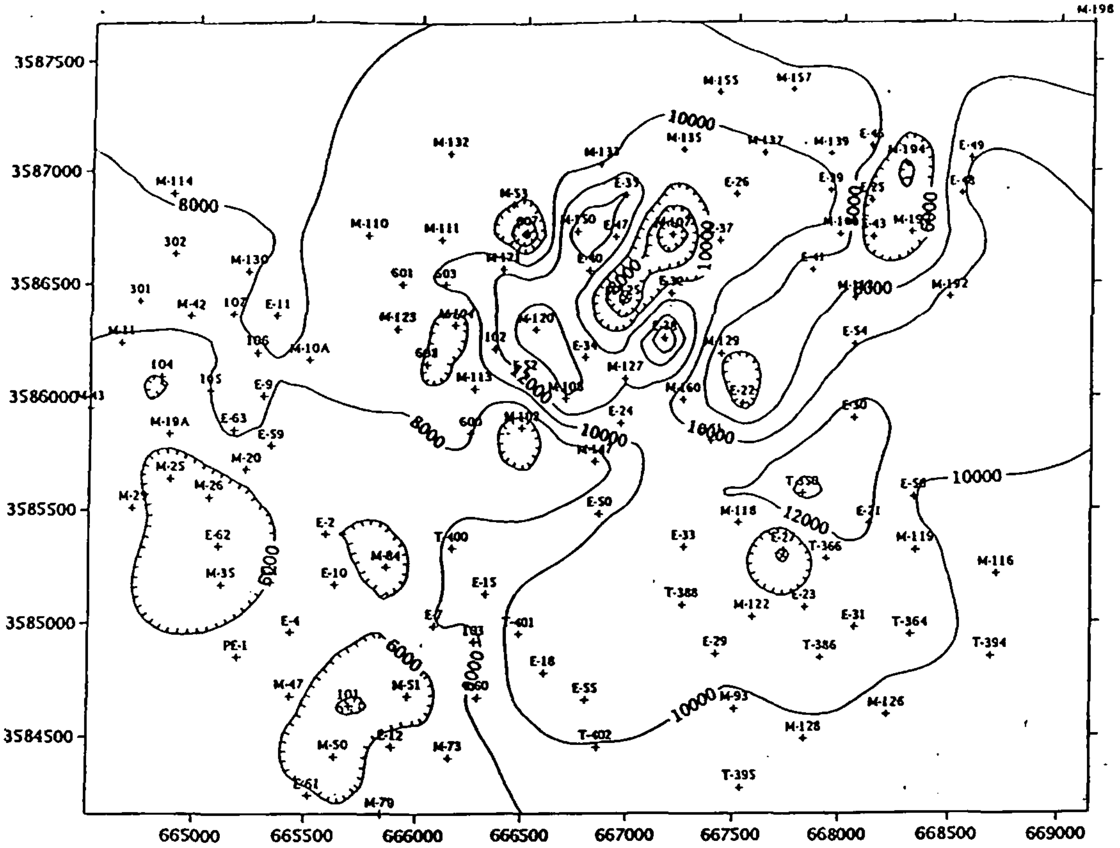


Figure 3.

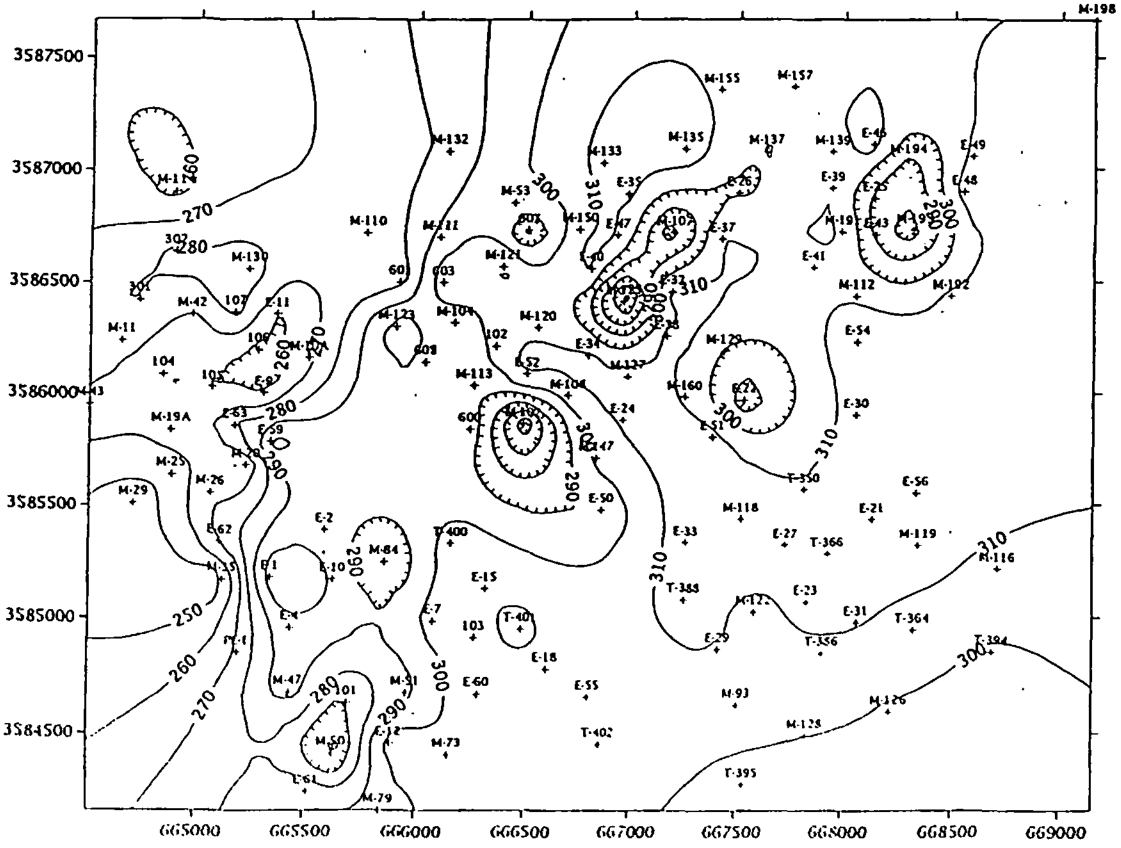


Figure 4.

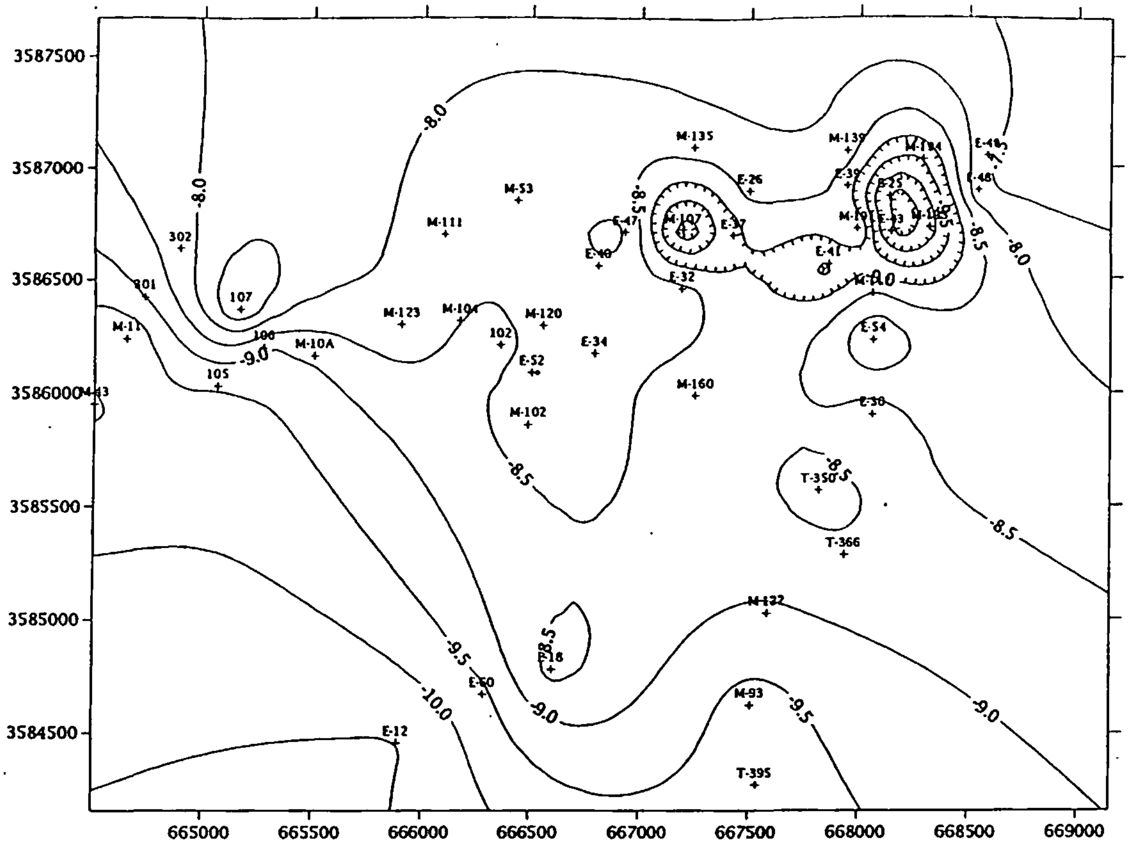


Figure 5.

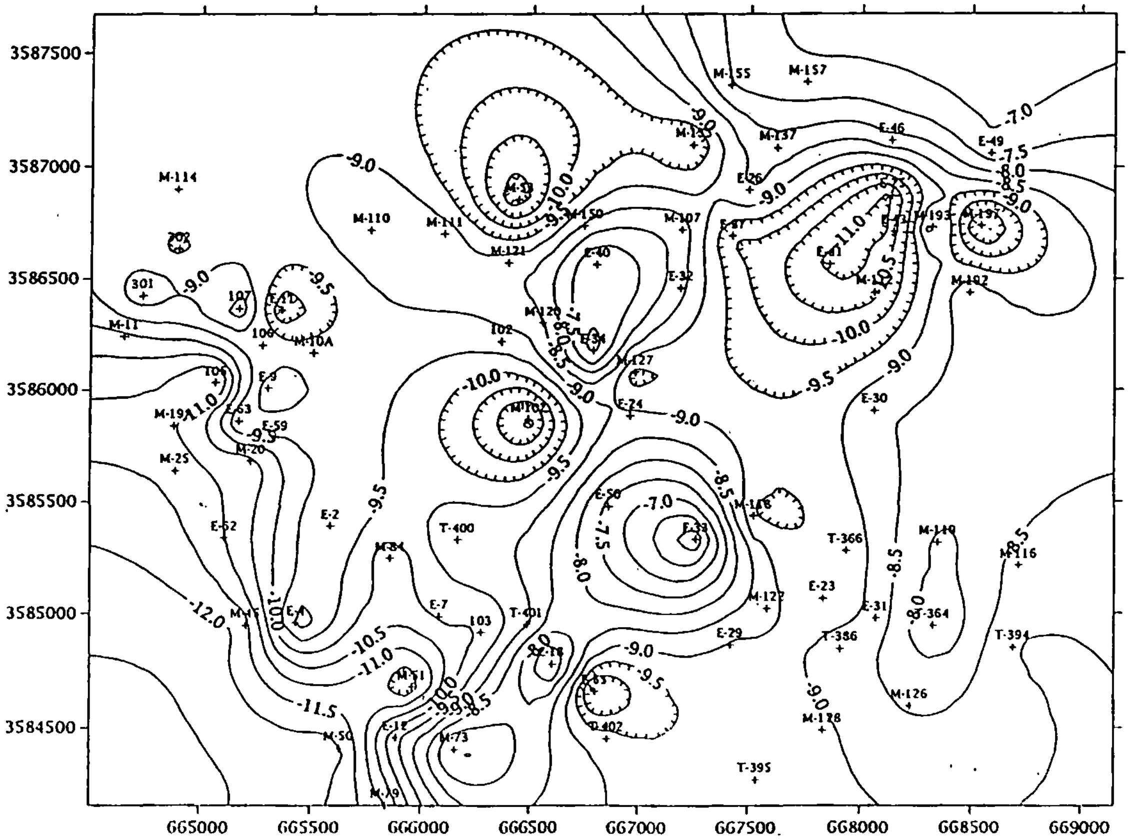


Figure 6.

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
15 November 1994

FEASIBILITY STUDY FOR USING EXCESS GEOTHERMAL POWER CAPACITY TO MANUFACTURE HYDROGEN

M. Fioravanti	C. Cadenas
P. Kruger	M. Rangel
GP, DOE	Gerencia, CFE

Background:

Excess baseload geothermal electric power capacity could be utilized as a renewable energy resource to manufacture hydrogen for use as an energy carrier. Hydrogen would be valuable as a load-leveling mechanism for geothermal power plants or as a replacement for fossil fuels in transportation applications. The lower incremental cost of surplus geothermal capacity should lower the unit production cost of hydrogen, thus improving the cost competitiveness of geothermal hydrogen with other energy scenarios. Other cost reductions for geothermal hydrogen would be the air quality benefit derived from reduction in air pollutants and the value of the co-produced oxygen during electrolysis.

Objective:

The objective of the joint study is a feasibility report of the technical and economic potential for developing sufficient excess capacity of geothermal electric power to produce hydrogen as a commercial product at selected geothermal fields under development by CFE in Mexico and to evaluate the potential for hydrogen fuel to provide air pollution abatement in urban areas such as the Mexico City air basin.

Program for 1994:

The analysis of potential excess geothermal electricity capacity that could be used for manufacture of hydorgen will be completed for the Tres Virgenes field in B.C.S. and applied to other geothermal fields in Mexico, e.g., Cerro Prieto. Data are needed on estimates of current and future installed capacity of the geothermal resource, estimates of the incremental cost of the excess power and its conversion to hydrogen by on-site electrolysis. Data are also needed on potential end-use markets for hydrogen and the associated environmental credits derived from health benefits and/or avoided costs of air pollution regulations.

Results to Date:

The feasibility study has identified three synergies between geothermal energy and hydrogen production:

1) incorporation of hydrogen production at geothermal sites can stimulate geothermal resource development, especially in remote areas with lower electricity demand or sites with commercially marginal resources;
2) incorporation of hydrogen production at geothermal sites allows for power plants to run at optimal baseload capacity; and
3) use of hydrogen produced from geothermal sites as a replacement for fossil fuels results in an energy pathway that produces a significant environmental benefit.

In addition, the major factors affecting cost of delivered hydrogen for end use have been identified, namely: cost of electricity, electrolyser technology, transport distance, and credit for environmental benefit.

The feasibility study has also identified geothermal hydrogen scenarios at three different scales appropriate for geothermal fields in Mexico: (1) a small, local (2-10 MWe) experimental facility; (2) a larger (100-300 MWe), regional energy/environmental network linking the Cerro Prieto field with polluted air basins near the US/Mexico border, such as Tijuana, San Diego, or Los Angeles; and (3) a nationwide (>1000 MWe) hydrogen infrastructure that could improve air quality for the Mexico City air basin.

Plans for 1995:

Further examination of the three identified geothermal hydrogen scenarios will detail critical economic, energy, and environmental parameters for each. Other issues affecting feasibility, including freshwater availability, environmental credits, and status of hydrogen technologies and markets will also be addressed for each scenario.

Geothermal Resources Council TRANSACTIONS, Vol. 18, October 1994

FIRST RESULTS OF DEEP EXPLORATORY DRILLING IN THE EL CEBORUCO GEOTHERMAL ZONE

J. Cesar Viggiano-Guerra and Luis C.A. Gutierrez-Negrin
Comision Federal de Electricidad, Alejandro Volta 655
Morelia, Mich., Mexico, C.P. 58290

ABSTRACT

Geological, geochemical, and geophysical studies have been made by the Comisión Federal de Electricidad (CFE) in the El Ceboruco Volcano geothermal zone. In order to complete its preliminary geothermal assessment before deep drilling, some shallow gradient wells were drilled and measured in this zone. The first deep exploratory well was recently completed to 2,800 meters depth. This deep well did not present high temperatures (maximum 112°C) nor important hydrothermal alteration at depth, meaning that the probable geothermal system is more restricted than anticipated.

Introduction

Over the past 10 years, the El Ceboruco Volcano, and the San Pedro Dome geothermal zones have been explored by the Comisión Federal de Electricidad (CFE: Federal Commission for Electricity) exploration staff. In addition to geological mapping, geochemical fluids analysis, geophysical surveys (including resistivity, magnetotelluria, gravimetry and magnetometry), and a number of shallow gradient wells were drilled to accomplish the exploration. More priority was given to the El Ceboruco area because of the volcanological evolution, structural framework, and apparent geothermal possibilities. As a result, a deep exploratory well, named CB-1, was drilled by end of 1993, and the beginning of 1994 to 2,800 meters depth.

In this paper we attempt to provide a short and preliminary synthesis of the lithological, mineralogical, and geothermal results of the well CB-1, as well as to sketch some useful lessons, especially concerning the hydrothermal mineralogy interpretation focused in further exploration in the zone.

Regional Geological Setting

The El Ceboruco Volcano, together with other Quaternary volcanic centers, is located at the western part of the Mexican Volcanic Belt (Figure 1), whose Plio-Quaternary calcalkaline activity is related to the subduction of the Cocos Plate beneath the North-American Plate, and to the aseismic and waning Rivera Plate, under the Jalisco Block along the Middle American Trench (Luhr et al., 1985). This process seems to be responsible of the volcanism at this place.

In addition, a triple junction apparently ocurrs 50 km southernly from Guadalajara City (Figure 1) as a consequence of that tectonic process, with a rather complicated evolution which includes the Chapala Graben toward the east, the Tepic-Zacoalco Graben in the northwest and the Colima Graben to the south (Luhr et al., 1985; Stock, 1993).

Locally, the El Ceboruco Volcano lies entirely on the northwestern portion of the Tepic-Zacoalco Graben, which seems to be an ongoing rifting zone since Pliocene (Luhr et al., 1985). Small volumes of unusual alkaline magmas have erupted in this graben, in close association with more abundant subduction-related calcalkaline magmas erupted by andesitic stratovolcanoes, like the El Ceboruco itself.

Alkaline magmas are varieties found in zones of active rifting elsewhere in the world. At the Tepic-Zacoalco Graben, their true origin, according to Luhr et al. (1985), may be due to the spreading ridge jumping which is being propagated at approximately about 10 to 12 million years ago from the South Pacific Rise in different stages. So, the East Pacific Rise segment bounded by the Rivera and Tamayo fracture zones, would be current in the process of jumping some 600 km eastward, to the site of the Colima Graben, thus, continuing the northward propagation of the ridge-segment jumps (see insert in Figure 1).

The El Ceboruco Volcano

Understanding of history of the El Ceboruco Volcano is a very important matter in order to better know the geothermal potential of the area. Nelson (1986) has carried out an exhaustive study of this volcano, focused on the volcanological mapping and petrological studies.

El Ceboruco is a middle-size stratovolcano, with 60 km^3 in volume; it is the only volcano with historic activity in this portion of the Mexican Volcanic Belt. Its eruptive history can

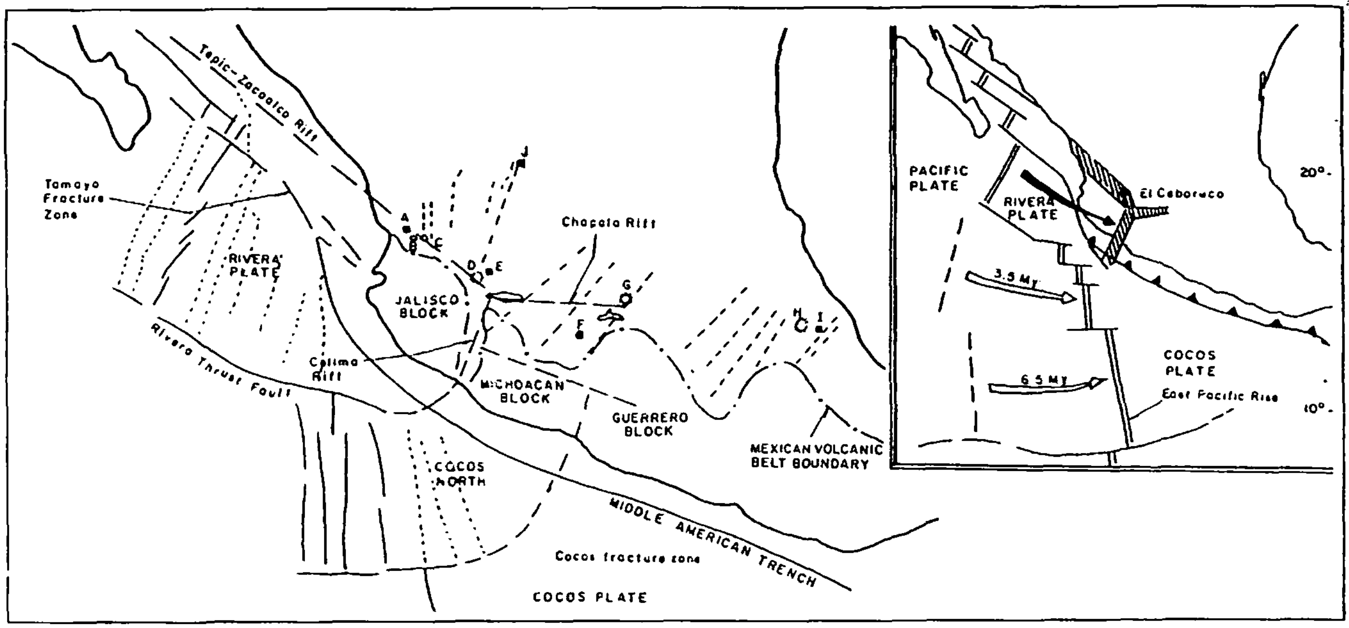


Figure 1. El Ceboruco regional tectonic framework. **LEGEND:** A. Tepic City, B. Sangangüey Volcano, C. El Ceboruco Volcano, D. La Primavera Caldera, E. Guadalajara City, F. Morelia City, G. Los Azufres, H. Los Humeros Caldera, I. Jalapa City, J. Zacatecas City. **INSERT** : Active rifting (dashed zone) as a result of a present spreading ridge-jumping. *(Data from Luhr et al., 1985, and Stock, 1993).*

be divided into three stages, which are included in Table 1 (after data from Nelson, 1986, and Romero and Palma, 1993).

Based upon the magma evolution, Nelson (1986) suggests the volcano could now be evolving toward a gass-bearing composition richer in SiO_2, and could erupt in coming days. He has estimated that there were at least eigth eruptions over the last 1,000 years. The last eruption which took place in 1870, left a thick (200 meters) dacitic flow on the southwestern flank of the volcano, a new eruptive event could happen in the next several years.

However, the volcanic history of the El Ceboruco Volcano makes it very feasible that the magmatic chamber of the volcano is at a depth and contains conditions to behave as a heat source for the probable geothermal system beneath it.

Exploratory Studies Prior Drilling

In addition to usual geological mapping, regional tectonic, and structural studies, geophysical surveys, with special emphasis on magnetotelluric and gravimetric studies, were achieved as in the El Ceboruco zone as in the Tepic-Zacoalco Graben. Magnetotelluric survey in El Ceboruco reported apparent important low resistivity anomalies located beneath the volcano and in two other areas. These anomalies were believed to be associated with the geothermal aquifer (Romero and Palma, 1993).

On the other hand, interpretation of the Bouguer Anomaly suggested a lithological basement underlaying those volcanic rocks belonging to El Ceboruco, that could represent rocks of the Tertiary Sierra Madre Occidental (SMO). The SMO is the largest ignimbritic province in the world, and outcrops about 4 km northeasternly of the El Ceboruco Volcano. An echelon fault array, dipping to the southwest and affecting rocks of the SMO, was interpretated. It was believed that these ignimbritic rocks could behave as a cap rock.

Geochemical analysis carried out in gases from fumaroles of the inner caldera and from the 1870 dacitic flow, point out the presence of both CO_2 and H_2S, being first the most abundant compound (Romero and Palma, 1993). Further data on fumaroles are also reported by Nelson (1986), with superficial temperatures ranging from 55°C to 92°C, making it the hottest related to the most recent flow (that of 1870).

Recently, a very small altered area, around 0.5 meters in diameter, located in the most recent crater, was sampled and studied by X Ray Difracction mineralogy (Izquierdo, 1993). The study reports plagioclase as well as cristobalite and kaolinite. Plagioclase is of primary origin, whereas the kaolinite and cristobalite were formed in a vadose zone due to condensation of steam.

Geothermal steam is invariably accompanied by a small portion of CO_2 and H_2S; the latter readily oxidizes, usually near the surface, to H_2SO_4 producing a strong acid that immediately attacks the surrounding rocks (Browne, 1990). Volcanic rocks, *e.g.* pumice and glass, are readily dissolved in a distinct fashion, producing the usual acid indicating assemblage of residual silica (but not sinter) with other minerals such as kaolinite, alunite, hematite, jarosite and pyrite.

However, the case herein reported only included kaolinite and cristobalite, as mentioned. This, in addition to the very

Table 1. Stages of the eruptive history of El Ceboruco.

STAGE	CHARACTERISTICS	CLASSIFICATION & MINERALOGY
1	▪ Formation of main cone. Lava flows 1-5 m thick, *aa* type.	Andesites (Pl + Cpx + Ol + Tmt) (40 km^3).
	▪ Outer caldera & dykes. Peripherical flows & scoria cones.	Similar andesites plus high alumina basalts.
	▪ Forming of C. Pochotero dome, C. Pedregoso & Destiladero flow.	Rhyolites & rhyodacites.
	▪ Jala pumices & Marquesado ashes, 1000 years ago.	Rhyolitic & rhyodacitic (2 km^3).
2	▪ Dos Equis dacitic dome into the outer caldera.	Dacites (Pl + Opx + Cpx + Il + Tmt) (1.3 km^3)
	▪ Inner caldera in the Dos Equis dome.	
	▪ Copales dacitic flow.	Dacites (+ glass + xenolites) (1.4 km^3)
3	▪ Andesitic dome at outer caldera.	Andesites (Pl + Cpx + Ol + Tmt).
	▪ Andesitic *aa* type lavas. North of volcano.	Andesites (Pl + Cpx + Ol + Tmt).
	▪ El Ceboruco flow (spongy andesites).	Andesites.
	▪ Historic eruption (1870). Flow 7.5 km long & 200 m thick.	Dacites (Pl + Opx + Cpx + G + Il + Tmt) (1.3 km^3)

NOTES: Pl = Plagioclase, Opx = Orthopriorxene, Cpx = Clinopioxene, G = Glass, Il = Ilmenite, Ol = Olivine, Tmt = Tianiferous magnetite.

restricted extension of the altered zone, leads us to think that the mass flow discharging of the probable deep reservoir is very low. This could reduce the geothermal potential of the zone, as it seems to be suggested by the results of the exploratory well.

Exploratory Drilling

The first deep exploratory well, named CB-1, is located approximately on the southwestern slope of the El Ceboruco Volcano, about 5 km away from its summit. Drilling of the CB-1 was preceded by a shallow (400 meters depth) gradient well, results of which are yet published (Viggiano, 1993). Both wells were drilled at the same site.

Well CB-1 reached 2,800 meters depth, but here are reported only first 2,240 meters, which is the depth with available results up to date. Every 10 meters cuttings were studied, as well as four from the five core samples, by using a petrographic microscope.

It is well known that there are always problems working with cuttings, particularly in this well where a mixture of air with mud (aerated fluid) was used as a drilling fluid; hence, this produced very small cuttings indeed. Nevertheless, a good view of rock textures and mineralogy was experienced.

Lithology

Figure 2 illustrates the primary petrology of the subsurface rocks cut by the well. Most of those rocks belong to the calcalkaline suite and are predominantly basalts, basaltic andesites and subordinate rhyolites, with different textural and mineralogical varieties. However, at least two horizons of volcanic aglomerates were found (Figure 2).

Noting of the lithogical sequence in that figure can be related to the SMO volcanics, as were expected prior to drilling. An ignimbritic rock was identified in the interval between 1,540 and 1,650 meters (Figure 2). Below this interval, cuttings included many fragments of ignimbrites, but predominately basalts and basaltic andesites. This led to the conclusion that numerous amounts of ignimbritic horizons had been intersected, and, therefore, the SMO series had been found. However, that abundance of ignimbritic chips seems to be a result of mixing of rocks that fell down during drilling, given the nature of the drilling fluid, instead of the presence of the SMO volcanics.

As for the ages of subsurface rocks penetrated by the well, some ideas are given in Figure 2, but without dating support.

Hydrothermal Mineralogy

Figure 3 shows the hydrothermal alteration interpreted from petrographic analysis. A striking feature for rocks from a geothermal well, is how few rocks have been intensively altered: most chips show only scarse alteration. Generally, the process of low intensity alteration is also reflected by the relative stability of primary minerals, for instance, the unaltered ferromagnesians.

In general, there are two different alteration regimes. One of them is localized from 420 to 650 meters depth, and is characterized by the illita + montmorillonite + quartz + epidote + calcite + pyrite + zeolites (probably laumontite and/or heulandite) assemblage. The other is localized from around 800 meters depth to the bottom, and is relatively unhomogeneous; is characterized by almost the same minerals but in lesser abundance than those of the first zone, with no epidote, nor illite, much less pyrite and much more chlorite (specially penninite) (Figure 3).

The deeper alteration zone is characterized also by the lack of veining, contrasting with the shallower one; this lack of cavities filling process probably indicates that there was a very low permeability at the moment of mineral deposition.

An immediate conclusion from such an alteration mineralogy, is that no important geothermal system has been active in the lower half of the well. The shallower interval 420 to 650 meters depth, however, presents a hydrothermal mineralogy typical of geothermal systems, whose temperatures were probably in excess of 230°C.

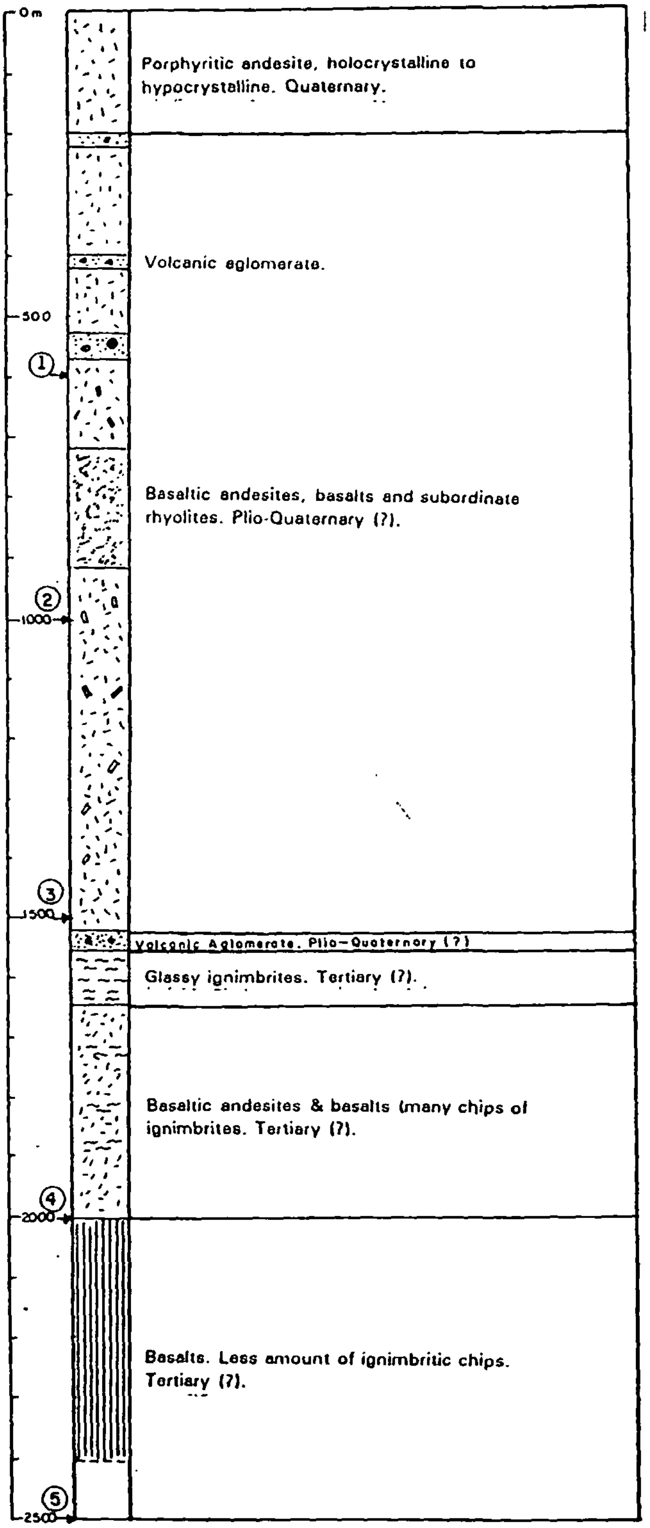


Figure 2. Simplified lithology of well CB-1. Core samples are indicated with arrows and numbers 1 to 4.

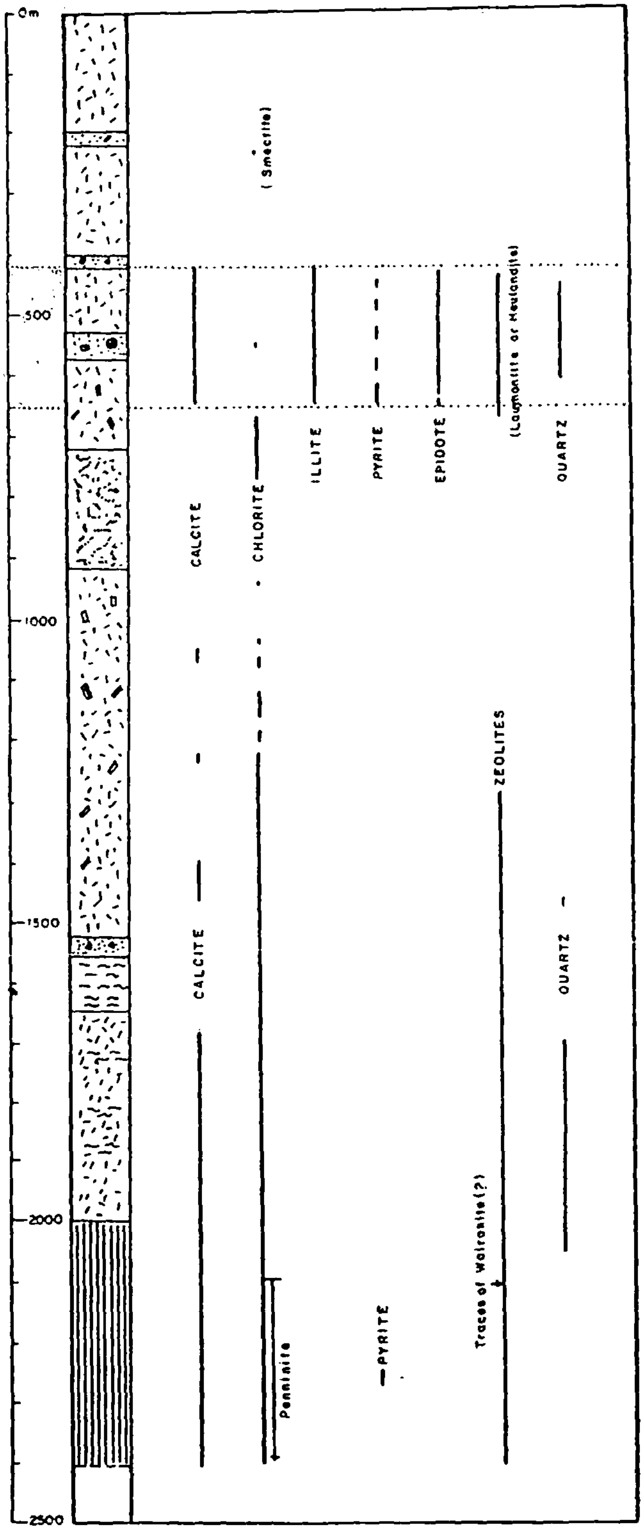


Figure 3. Hydrothermal mineralogy of well CB-1. High alteration interval is marked with dots.

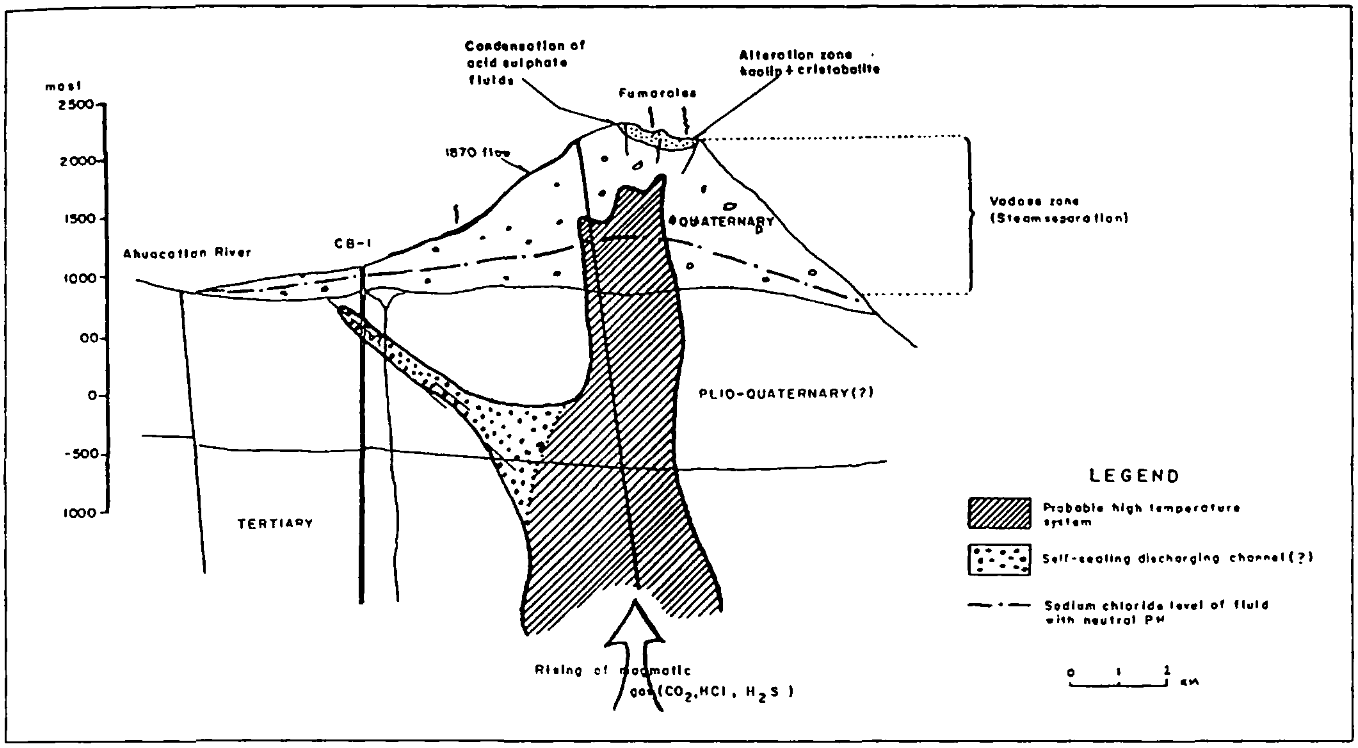


Figure 4. Preliminary flow model for El Ceboruco.

It is appropriate to mention that the present, maximum measured temperature in the well was around 112°C.

Flow Model for El Ceboruco

After a previous model of the El Ceboruco Volcano (Viggiano, 1993), and taking into account the mentioned results of well CB-1, it is possible that this zone would be a high relief system, which flashes steam above the sodium chloride water table. Its remaining temperature would serve as a heat source, which is capable to heat an aquifer forming an apparently restricted geothermal system (Figure 4).

Geothermal fluids from such a system upflow through recent lava conduits, faults and fractures, and form in time, a steam or vadose zone with variable amounts of H_2S and CO_2 discharging as fumaroles onto the surface. The H_2S oxidizes giving a corrosive acid that attacks the rocks to produce cristobalite and kaolinite among others. Superficial discharge was very limited, as far as it can be judged after the surface alteration. Deep lateral extension of the system is unknown, but probably was partially extended through the future site of well CB-1 as a narrow, shallow discharge zone (Figure 4).

That discharge has ceased today, but could explain the mineral alteration zone found in the CB-1 between 420 and 650 meters depth. The hydrothermal mineral assemblage, headed by epidote, represents past temperatures over 230°C, as mentioned above. Upflow could happen through a fault zone with no superficial evidence, and would then be thoroughly self-sealed and cold.

The rest of the alteration represents a regional low temperature (<150°C) aquifer, according to the mineral characterized by heulandite (?), which is presently quite impervious. Notice, however, that these alteration processes took place below the sodium chloride water table (Figure 4).

Outstanding Remarks

- In spite of unsuccessful geothermal results of the first deep exploratory well in the El Ceboruco Volcano, its volcanological and structural features allow us to assume the presence of an active, high temperature geothermal system beneath it. This probable system seems to be more restricted than anticipated to the central volcanic conduit, as has been indicated by well CB-1, but could be large enough in dimensions to be used in a small geothermal development. That restriction must be taken into account however, if a second exploratory well is drilled near the volcano.
- Previous geological and structural interpretations on the regional framework of the El Ceboruco Volcano must be reviewed, according to the lithology found in the well. It is very important to understand the SMO volcanics, which outcrops 8 km away from the well.
- Standard geophysical techniques used in decision making to locate additional exploratory wells, must be carefully

considered. Especifically, the well CB-1, which was located among others, on the basis of an apparently important resistivity anomaly after a magnetotelluric survey, but, was not a cold nor hot water, nor an alteration zone, at depth, which could be associated to that anomaly.

References

Browne, P.R.L., (1990). Hydrothermal alteration and geothermal systems. University of Auckland, New Zealand, Publication, p. 86-102.

Izquierdo, G., (1993). Letter communication.

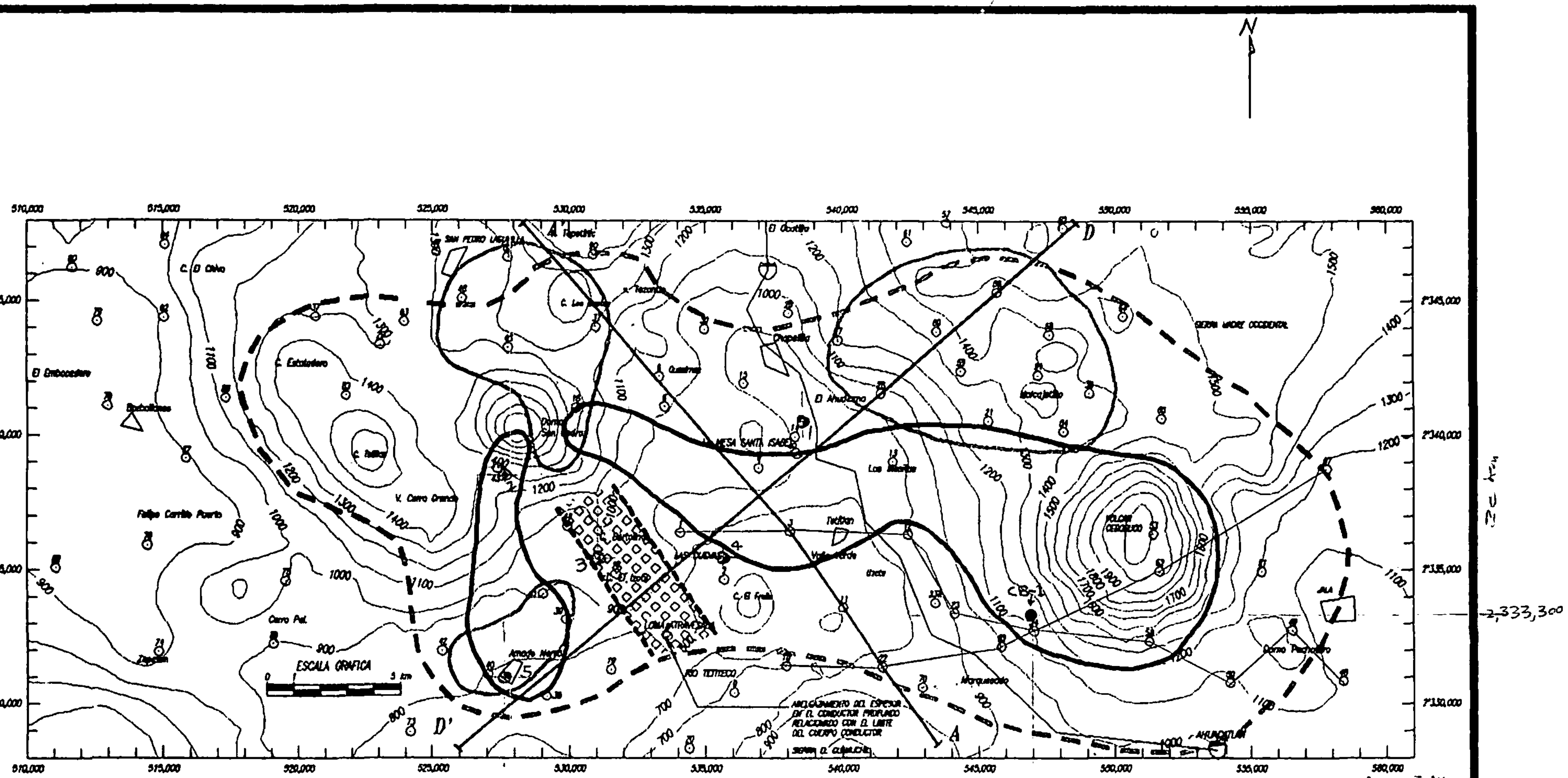
Luhr, J.F., S.A. Nelson, J.F. Allan and I.S.E. Carmichael, (1985). Active rifting in Southeastern Mexico: Manifestation of an incipient eastward spreading ridge jump. *Geology*, v. 13, p. 54-57.

Nelson, S.A., (1986). Geología del Volcán Ceboruco, Nay., con una estimación de riesgos de erupciones futuras. UNAM, Revista del Instituto de Geología, v. 6-2.

Romero R., F., y S.H. Palma G., (1993). Propuesta para la localización del pozo CB-1. CFE, Residencia ElCeboruco, Informe 03/93. Unpublished.

Stock, J.M., (1993). Tectónica de placas y la evolución del Bloque Jalisco, México. *GEOS*, Bol. de la Unin Geofísica Mexicana, v. 13-3.

Viggiano G., J.C., (1993). Modelo conceptual aproximado del yacimiento geotérmico en el Volcán Ceboruco.Geotermia, 9-3.



51 km E-W

SIMBOLOGIA

highway
CARRETERA FEDERAL

▲ MANANTIAL TERMAL
spring

CUERPO ANOMALO
anomalous body

ZONA CONDUCTORA A UNA PROFUNDIDAD MAYOR DE 100 mts.
conductive at a depth greater than 100 m

● 5 T.G. Hole.

547

LOCALIDAD
locality

SONDEO MAGNETOTELURICO

SECCION MAGNETOTELURICA

SECTORES CONDUCTORES CON EL MAXIMO ESPESOR (>400 mts.)
sector with maximum thickness (>400m)

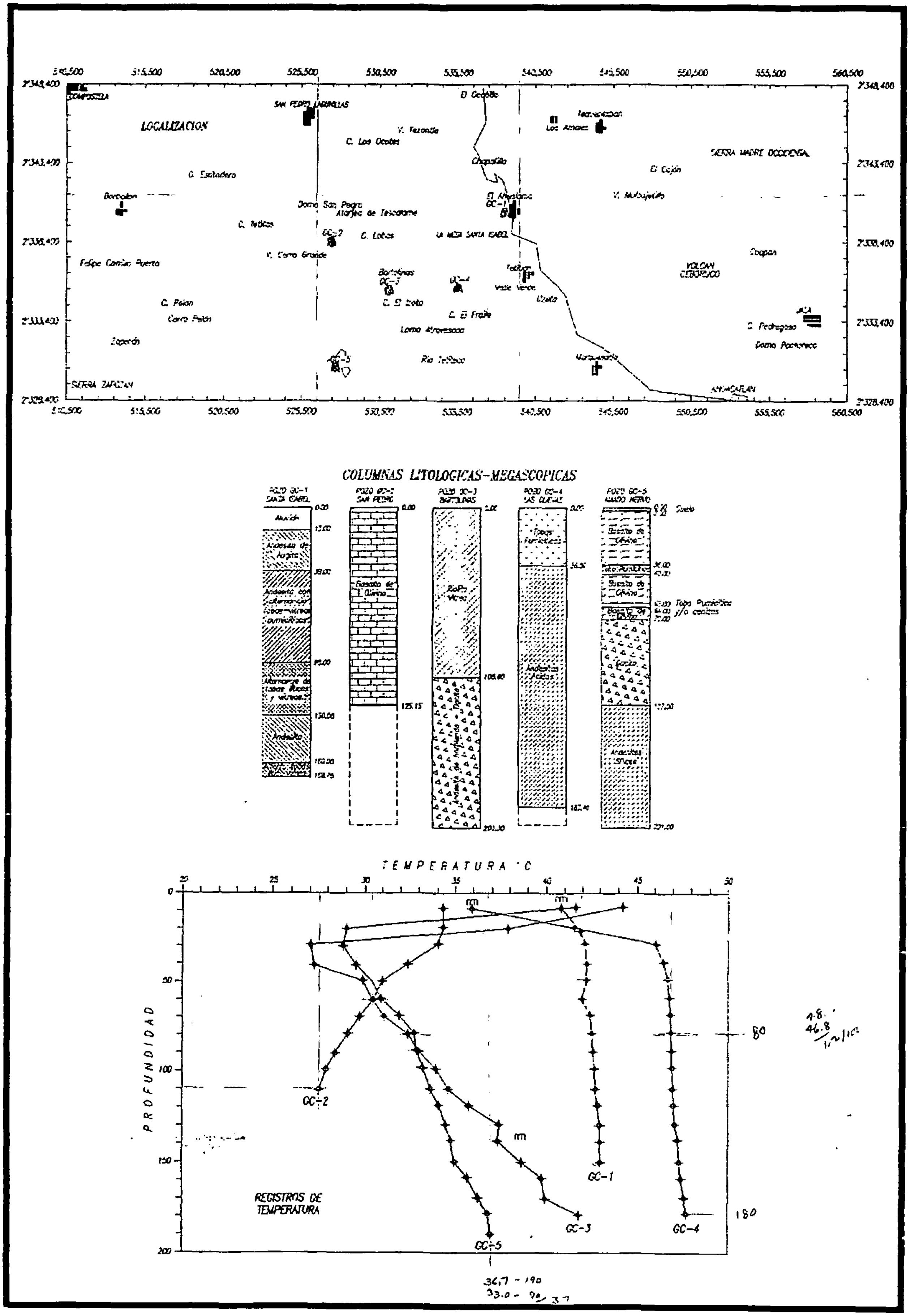
51 x 20 Km = 1020 Km²

scale: ~1:250,000

X = 400m T.G. hole ?

FIGURA 8.- SECTORES GEOELECTRICAMENTE ANOMALOS DE ACUERDO CON LOS DATOS MAGNETOTELURICOS
agreement

H/R



80

180

48.
46.8
1.2/10²

34.7 - 190
33.0 - 90 / 3.7

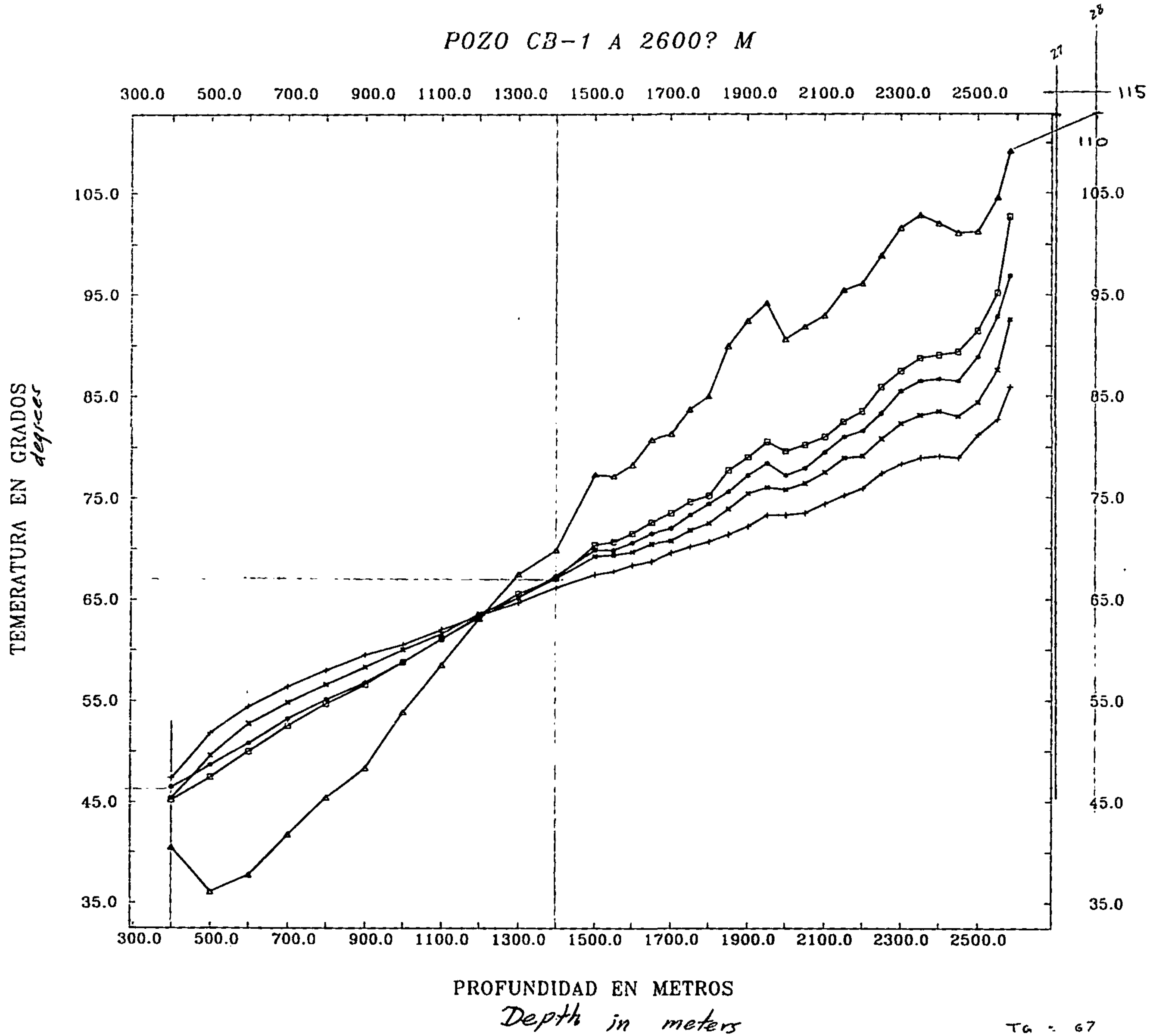
FIGURA 13.- CARACTERISTICAS GENERALES DE LOS POZOS DE GRADIENTE

12

14

$\frac{182\ Km^2}{2} = 91\ Km^2$

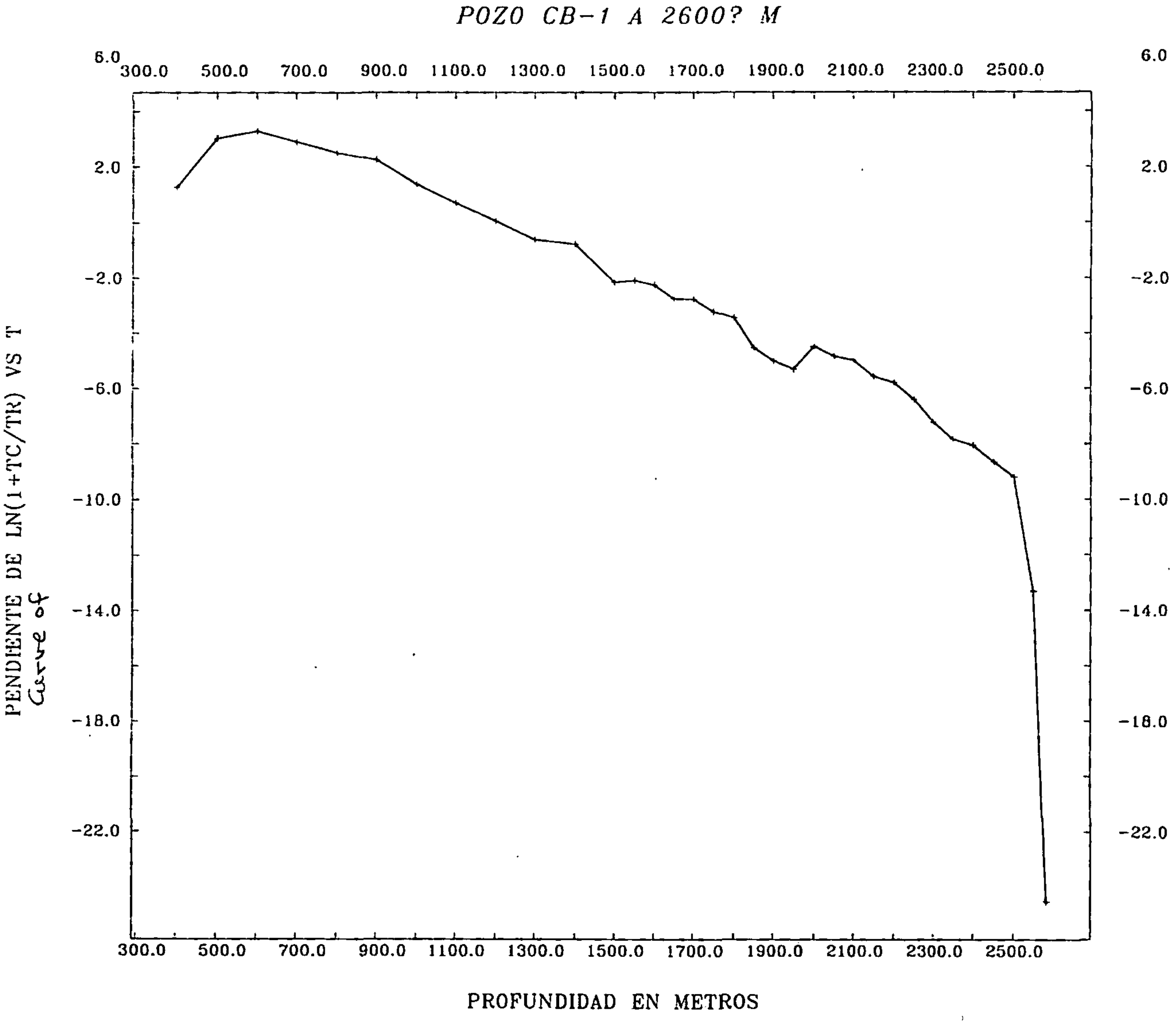
POZO CB-1 A 2600? M



$$\text{TG } 400\text{-}1400 = \frac{67 - 46}{21} \,/\text{Km}$$

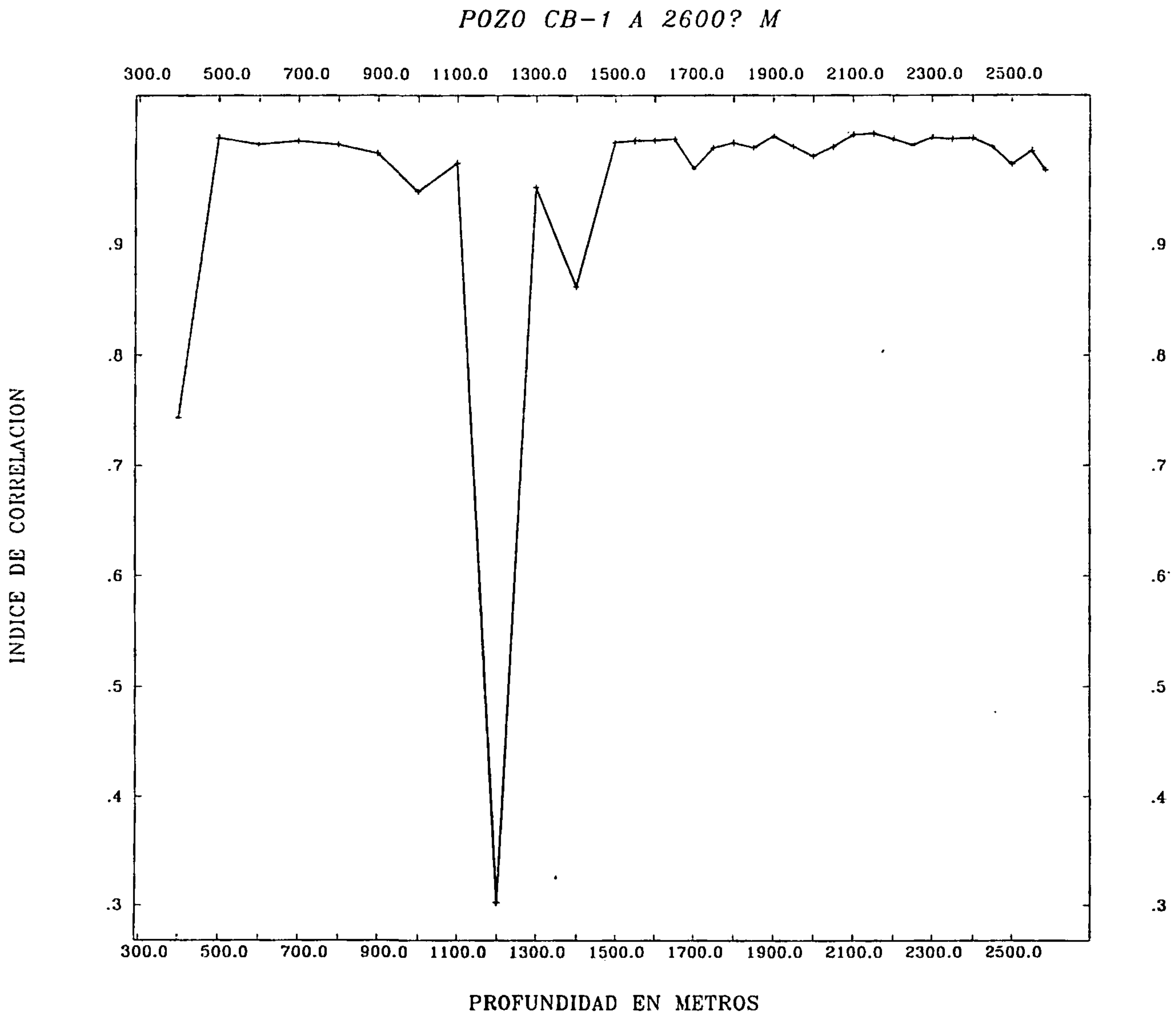
$$\text{TG } \begin{array}{l} 2800 = 112 \\ 1400 = \underline{67} \end{array} \quad 55\,/1$$

=



POZO CB-1 A 2600? M

4/2


POZO CB-1 A 2600? M
300.0
500.0
700.0
900.0
1100.0
1300.0
1500.0
1700.0
1900.0
2100.0
2300.0
2500.0
.9
.8
.7
.6
.5
.4
.3
INDICE DE CORRELACION
PROFUNDIDAD EN METROS

UURI

University of Utah Research Institute
Earth Science Laboratory
391 Chipeta Way, Suite C
Salt Lake City, UT 84108-1295
USA

Phone: 801-584-4422 FAX: 801-584-4453

Facsimile (FAX) Cover Page

From: Howard Ross, Phil Wannamaker Date: September 7, 1994

To: **Ing. Saul Venegas S. Salgado**
FAX: 524-43-14-4735

Number of pages including this one: **4**

Message or Comments:

Original to follow by mail.

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-524-3422

September 6, 1994

Ing. Saul Venegas Salgado
Jefe del Departamento de Exploracion
Gerencia de Proyectos Geotermoelectricos
Comision Federal de Electricidad
Morelia Michoacan
Mexico

Dear Sr. Venegas:

Dr. Wannamaker's comments describing his review of the magnetotelluric (MT) data for the Ceboruco-San Pedro geothermal area are transmitted herewith. Some additional comments follow.

A favorable time for a CFE geophysicist to visit UURI and discuss the MT interpretation would be October 5-7, immediately after the GRC meeting in Salt Lake City. Dr. Wannamaker is preparing for an extended field survey out of the country and his time in Salt Lake City will be limited. Perhaps a few numerical models could be computed at this time, if desired.

We do not have GEOTOOLS running on our computer system at the present time. If the CFE geophysicist intends to process or model any MT data it would be necessary to bring the MT data on disk as an ASCII file.

We would like to know the exact (map) location of the deep drill hole in order to evaluate the drill results in terms of nearby MT soundings and gravity and magnetic expressions.

Dr. Wannamaker has selected two short technical papers (Pellerin et al., 1993, and Simmons and Browne, 1990) which relate to low-resistivity zones due to altered volcanics which may relate to the Ceboruco-San Pedro case. We will send these to you under separate cover.

Sincerely,

Howard Ross
Howard P. Ross
Section Head/Applied Geophysics

cc: P.M.Wright
P.E.Wannamaker

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

September 7, 1994

Ing. Saul Venegas Salgado
Jefe del Departamento de Exploration
Gerencia de Proyectos Geotermoelectricos
Comision Federal de Electricidad
Morelia Michoacan
Mexico

Dear Sr. Venegas,

I have finally had an opportunity to examine the magnetotelluric (MT) data and interpretations from the Ceboruco-San Pedro geothermal area sent to our lab last May. Materials include a report on the state of the exploration in 1992 authored by yourself and Ing. Arellano, a lengthy interpretation dated November 1991 by Messrs. Copley and Orange of AOA, Inc., and an additional report dated April 1993 by Ing. Guzman. A lithologic log of deep well CB-1 was received also although we were not able to find a precise location for it.

The interpretation of Copley and Orange, summarized in the state-of-exploration report, is the most quantitative and detailed. Overall, I find it to be competent and credible. The response of most of the 93 soundings distributed over 1250 km^2 is dominated by the presence of a low resistivity layer at a depth of a few hundred meters typically. This was judged by Copley and Orange to represent a stratigraphic horizon of altered volcanics and derived sediments. I agree with that conclusion and note that rhyolitic tuffs especially have a tendency to be altered and conductive. Two examples of this with which we are familiar include the northwest U.S. Cascades (Wannamaker et al., 1989, J. Geophys. Res.) and Long Valley caldera (Wannamaker et al., 1991, Geophysics). Such horizons can be of economic geothermal interest <u>on a local basis</u>, such as in the latter example, but this usually must be established by means independent of MT. Generally, these conductive horizons are not of interest in exploring for geothermal energy.

Copley and Orange go on to identify three intermediate-scale areas of anomalous behavior which they suggest may have some geothermal significance. These are north of Ceboruco volcano, near Amado Nervo, and south of San Pedro volcano. The identification was based upon the so-called E-parallel (to local strike) or transverse electric (TE) mode of response showing a more pronounced apparent resistivity minimum at intermediate frequencies, while the E-perpendicular or transverse magnetic (TM) mode showed decreasing apparent resistivities towards the lowest frequencies. A simple 2-D model given by Copley and Orange reproduced the effect approximately using a conductive dike between shallow and deeper conductive layers, such as exist widely over the area. However, it was necessary to include a broadening base to the dike-like structure in order to reproduce the TM response at distances of several km from the dike. It also is not clear whether the narrowest and shallowest portions of the dike are required to reproduce the TE characteristics fundamentally. To me, it appears equally likely that buried 'topography' on the subsurface conductive stratum, subsequently covered by resistive lava flows, may be the geologic cause of this particular set of MT responses. It thus would be very risky to pursue these anomalous areas for geothermal resources without strong corroborating evidence.

In the western United States, widely-spaced MT soundings in a reconnaissance survey have not proved valuable in narrowing the search for geothermal resources. Value has been found in applying MT later in the exploration sequence for specific structural studies of areas identified through independent means, such as high-temperature alteration or spring geochemistry. In particular, MT appears to be the superior electrical method for attempting to resolve any deeper, more narrow and subtle, conduit zone for upwelling fluids beneath a cap of clay alteration. We enclose a short model study of such a structure for several electrical methods based upon a concept for geothermal systems of New Zealand.

I hope these comments will be of some value in understanding the magnetotelluric survey in question and the MT method in general. Please feel free to contact Dr. Ross or me directly with any other questions.

Yours sincerely,

Phil Wannamaker

Philip E. Wannamaker, Ph.D.

cc. H. P. Ross
P. M. Wright

```
*************** -COMM.JOURNAL- ******************** DATE SEP-08-1994 ***** TIME 08:58 **** P.1

   MODE = TRANSMISSION                            START=SEP-08 08:37     END=SEP-08 08:58

  NO.     COM   SPEED/NTWK  STATION NAME/        PAGES    PRG.NO.   PROGRAM NAME
                            TELEPHONE NO.

 001       OK   ☎           90115243144735       004

                                                     -U OF U RESEARCH          -

***************************************(  FAX-310  V2.12)* -       801 584 4453- ************
```

STANFORD UNIVERSITY
Department of Civil Engineering

Terman Engineering Center
Stanford, California 94305-4020
Telex 348402 STANFRD STNU
Fax 415-725-8662

CFE-DOE GEOTHERMAL AGREEMENT

MEMORANDUM

21 July 1994

To: DOE Participants
From: P. Kruger
Subject: Next Technical Meeting

At a meeting with CFE in April, 1994, the following items were covered, which are of interest to participants in the DOE-CFE Geothermal Agreement:

(1) Completion of the List of Projects for 1994. An amended copy is enclosed.
(2) Accord to renew the Agreement for another 5 years. The paperwork between DOE and CFE is underway.
(3) Accord to convene the Third Technical Meeting; tentatively scheduled for 15-16 November 1994 in San Diego, CA.

With respect to item (3), accord was also reached to have substantive Progress Reports at the technical meeting. CFE will endeavor to have each P.I. contact his counterpart to initiate or continue communications. It was recommended that each DOE P.I. do likewise. Further details on the meeting will be distributed when available.

Paul Kruger
telephone: 415+725-2382

Distribution:		Fax:
J. Mock,	for DOE	(202) 586-5124
M. Lippmann,	LBL	(510) 486-5686
P. Kruger,	SGP	(415) 725-8662
J. Lund	OIT	(503) 855-1754
J. Moore,	UURI	(801) 584-4453
P. Wanamaker,	UURI	(801) 584-4453
M. Fioravanti,	SGP	(415) 725-8662
G. Nash,	UURI	(801) 584-4453
G. Horton,	Unocal	(707) 545 8746

DOE-CFE Geothermal Agreement

Project Summaries
April, 1994

Cerro Prieto and Los Azufres

1. Analysis of the Behavior of Wells from Different Areas of the Cerro Prieto Geothermal Field.
   M.J. Lippmann, LBL — H. Gutierrez P., CP
   A.H. Truesdell, Cons. — M.O. Ribo, CP

2. Chemical Reservoir Engineering at Selected Loa Azufres Production Wells.
   P. Kruger, SGP — E. Sanchez, LAz

3. Direct Utilization of Geothermal Energy at Cerro Prieto and Los Azufres.
   J.W. Lund, GHC — M.A. Rangel, Ger

New Fields

4. Geochemical Studies - Tres Virgenes Geothermal Field.
   J.N. Moore, UURI — S. Venegas S., Ger

5. Geophysical Studies - Ceboruco Geothermal Reconnaissance Area.
   P.E. Wanamaker, UURI — J.F. Arellano G., Ger
   H.P. Ross, UURI

6. Feasibility Study for Using Excess Geothermal Power Capacity to Manufacture Hydrogen (at Tres Virgenes and Ceboruco).
   M. Fioravanti, SGP — M. Rangel, Ger
   P. Kruger, SGP

General Studies

7. The Joint Testing of Remote Sensing Techniques and Equipment for Use in Geothermal Exploration.
   G.D. Nash, UURI — G. Ramirez, Ger

8. Hydrogen Sulfide Gas Abatement for CFE Geothermal Plants.
   G. Horton, Unocal — B. Terrazas, CP
   M. Barnes, Unocal
   D. Gallup, Unocal

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-584-4422

MEMORANDUM

TO: John E. Mock, Director
Geothermal Division

FROM: Howard Ross

SUBJECT: Project Plans, Joint DOE/CFE Research Projects

DATE: February 18, 1994

Enclosed are Project Plan Summaries for the three projects which UURI and CFE will undertake, based on our discussions in Mexicali, Mexico on January 25, 1994. Please let me know if you need additional information.

Howard

Geochemical Studies
Tres Virgenes Geothermal Field

Joseph N. Moore
UURI
DOE

Saul Venegas Salgado
Gerencia
CFE

Background:

Tres Virgenes is one of several potential high temperature geothermal resources that is currently being explored by CFE. This geothermal system, which is associated with young volcanic activity, is developed within the granitic basement rocks. One deep exploratory well has been drilled but the well was not productive. A second well is currently being drilled.

Objectives:

Granitic host rocks throughout the world have proven to be difficult to explore and develop because of their inherently low permeabilities. Exploration of these reservoirs is further hindered by the common presence of multiple hydrothermal events that make the normally utilized mineralogic indicators of permeability difficult to interpret. Despite these difficulties, granitic reservoirs have proven to be attractive targets in the Unites States (e.g. Coso, Steamboat Hot Springs, Roosevelt Hot Springs, The Geysers) and Guatemala.

The joint study we propose has two major objectives. First, it will directly assist CFE in their exploration program of Tres Virgenes. Secondly, it will provide DOE and the U. S. industry with important new data on the physical and chemical characteristics of granitic reservoirs. These data will assist in both the development of our existing fields and in the exploration of new systems where U. S. interests are involved (e.g. Meager Creek, British Columbia).

Program for 1994:

We propose to jointly collaborate on geologic and geochemical studies of Tres Virgenes. UURI will work with CFE geologists to determine the mineralogies of the altered rocks and their significance, develop a better understanding of the permeability structure of the reservoir, and characterize the chemical evolution and characteristics of the thermal system. CFE will provide samples of the rocks and fluids to UURI. We will conduct petrographic (thin section, X-ray diffraction, and SEM) and fluid inclusion analyses in support of the work being conducted by CFE. CFE and UURI will jointly prepare a report on the results of this work upon completion of the studies.

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
15 FEBRUARY 1994

GEOPHYSICAL STUDIES
CEBORUCO GEOTHERMAL RECONNAISSANCE AREA

Phillip E. Wanamaker
Howard P. Ross
UURI
DOE

Jose Francisco Arellano Guadarrama
Senior Geophysicist
Gerencia
CFE

Background:

UURI and CFE completed cooperative geophysical studies of the Los Azufres geothermal area in an earlier DOE-CFE Cooperative Agreement, and these were reported in the 1989 DOE-CFE Research Proceedings. The Ceboruco area, within the western Neovolcanic Belt, was identified as a promising geothermal area for additional geophysical studies during the 1989-1994 agreement. CFE completed extensive gravity, aeromagnetic, and magnetotelluric (MT) studies in the greater Ceboruco area (30-40 km N-S by 40-50 km E-W) but UURI was unable to participate due to lack of project funding. Initial drilling results, including a test hole 1800 m deep sited on MT results, have been disappointing and CFE geophysicists have requested a review of contractor geophysical data, interpretations, and exploration strategy.

Objective:

This joint study will review the exploration strategy in general, and the MT data and interpretation in particular in the Ceboruco area of the prospective western Neovolcanic Belt. The identification of any problem areas will improve exploration results within this province, and perhaps the Cascades in the western United States.

Program for 1994:

To proceed in this research with the most efficiency, CFE will first submit gravity, aeromagnetic, geologic, MT, TDEM and other data in hardcopy for UURI review and study. UURI will complete a preliminary data review and identify specific MT data for reinterpretation. CFE will select key digital data and supporting information and bring these to UURI. A CFE geophysicist will spend one to two weeks at UURI reviewing MT data with Phil Wannamaker and completing new 1-D (and 2-D, if practical) interpretations. CFE and UURI geophysicists will complete a report describing new results and recommendations for future studies and improved exploration efforts.

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
15 FEBRUARY 1994

THE JOINT TESTING OF REMOTE SENSING TECHNIQUES AND EQUIPMENT FOR USE IN GEOTHERMAL EXPLORATION

Gregory D. Nash
UURI
DOE

Jose Francisco Arellano Guadarrama
Senior Geophysicist
Gerencia
CFE

Background:

UURI and CFE conducted a joint remote sensing study for the Los Azufres Geothermal Field in an earlier DOE-CFE Cooperative Agreement with the findings being reported in the 1989 DOE-CFE Research Proceedings. This study led to the conclusion that remote sensing techniques can be useful in geothermal exploration. It was shown that remote sensing can be effective in the early phases of exploration, particularly in determining hydrothermally altered zones and geologic structures conducive to hydrothermal fluid circulation. It was also stated that remote sensing data can be an important addition to a total exploration program when added as a correlative component to other geologic and geophysical data.

Objective:

This study will evaluate remote sensing data for an area chosen by CFE. The area will be delineated by the CFE with a universal coordinate system such as latitude and longitude or UTM. UURI personnel will then determine the availability, quality and cost of the data. This will allow CFE to review their options and request the data of their choice. One or more representatives of CFE will then travel to UURI for interactive work with UURI personnel in processing and interpreting the data. This will also allow the CFE personnel to evaluate various remote sensing and GIS hardware and software platforms for potential integration into the CFE system in the future.

Program for 1994:

The data for the chosen location(s) will be interactively processed by both UURI and CFE personnel to determine geomorphic indications of subsurface structure and to map hydrothermally altered areas. The processed data will then be added to a GIS database to allow the easy integration of other geologic and geophysical data for correlation purposes. In addition, the CFE personnel will be given an introduction to the use of hyperspectral (high spectral resolution) data in exploration. A report will then be written jointly by participating UURI and CFE investigators describing the results of the study and recommendations for future studies.

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-584-4422

MEMORANDUM

TO: John E. Mock, Director
Geothermal Division

FROM: Howard Ross

SUBJECT: Project Plans, Joint DOE/CFE Research Projects

DATE: February 18, 1994

Enclosed are Project Plan Summaries for the three projects which UURI and CFE will undertake, based on our discussions in Mexicali, Mexico on January 25, 1994. Please let me know if you need additional information.

Howard

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
15 FEBRUARY 1994

GEOPHYSICAL STUDIES
CEBORUCO GEOTHERMAL RECONNAISSANCE AREA

Phillip E. Wanamaker Howard P. Ross UURI DOE	Jose Francisco Arellano Guadarrama Senior Geophysicist Gerencia CFE

Background:

UURI and CFE completed cooperative geophysical studies of the Los Azufres geothermal area in an earlier DOE-CFE Cooperative Agreement, and these were reported in the 1989 DOE-CFE Research Proceedings. The Ceboruco area, within the western Neovolcanic Belt, was identified as a promising geothermal area for additional geophysical studies during the 1989-1994 agreement. CFE completed extensive gravity, aeromagnetic, and magnetotelluric (MT) studies in the greater Ceboruco area (30-40 km N-S by 40-50 km E-W) but UURI was unable to participate due to lack of project funding. Initial drilling results, including a test hole 1800 m deep sited on MT results, have been disappointing and CFE geophysicists have requested a review of contractor geophysical data, interpretations, and exploration strategy.

Objective:

This joint study will review the exploration strategy in general, and the MT data and interpretation in particular in the Ceboruco area of the prospective western Neovolcanic Belt. The identification of any problem areas will improve exploration results within this province, and perhaps the Cascades in the western United States.

Program for 1994:

To proceed in this research with the most efficiency, CFE will first submit gravity, aeromagnetic, geologic, MT, TDEM and other data in hardcopy for UURI review and study. UURI will complete a preliminary data review and identify specific MT data for reinterpretation. CFE will select key digital data and supporting information and bring these to UURI. A CFE geophysicist will spend one to two weeks at UURI reviewing MT data with Phil Wannamaker and completing new 1-D (and 2-D, if practical) interpretations. CFE and UURI geophysicists will complete a report describing new results and recommendations for future studies and improved exploration efforts.

PROJECT SUMMARY
DOE-CFE GEOTHERMAL AGREEMENT
15 FEBRUARY 1994

THE JOINT TESTING OF REMOTE SENSING TECHNIQUES AND EQUIPMENT FOR USE IN GEOTHERMAL EXPLORATION

Gregory D. Nash
UURI
DOE

Jose Francisco Arellano Guadarrama
Senior Geophysicist
Gerencia
CFE

Background:

UURI and CFE conducted a joint remote sensing study for the Los Azufres Geothermal Field in an earlier DOE-CFE Cooperative Agreement with the findings being reported in the 1989 DOE-CFE Research Proceedings. This study led to the conclusion that remote sensing techniques can be useful in geothermal exploration. It was shown that remote sensing can be effective in the early phases of exploration, particularly in determining hydrothermally altered zones and geologic structures conducive to hydrothermal fluid circulation. It was also stated that remote sensing data can be an important addition to a total exploration program when added as a correlative component to other geologic and geophysical data.

Objective:

This study will evaluate remote sensing data for an area chosen by CFE. The area will be delineated by the CFE with a universal coordinate system such as latitude and longitude or UTM. UURI personnel will then determine the availability, quality and cost of the data. This will allow CFE to review their options and request the data of their choice. One or more representatives of CFE will then travel to UURI for interactive work with UURI personnel in processing and interpreting the data. This will also allow the CFE personnel to evaluate various remote sensing and GIS hardware and software platforms for potential integration into the CFE system in the future.

Program for 1994:

The data for the chosen location(s) will be interactively processed by both UURI and CFE personnel to determine geomorphic indications of subsurface structure and to map hydrothermally altered areas. The processed data will then be added to a GIS database to allow the easy integration of other geologic and geophysical data for correlation purposes. In addition, the CFE personnel will be given an introduction to the use of hyperspectral (high spectral resolution) data in exploration. A report will then be written jointly by participating UURI and CFE investigators describing the results of the study and recommendations for future studies.

Geochemical Studies
Tres Virgenes Geothermal Field

Joseph N. Moore
UURI
DOE

Saul Venegas Salgado
Gerencia
CFE

Background:

Tres Virgenes is one of several potential high temperature geothermal resources that is currently being explored by CFE. This geothermal system, which is associated with young volcanic activity, is developed within the granitic basement rocks. One deep exploratory well has been drilled but the well was not productive. A second well is currently being drilled.

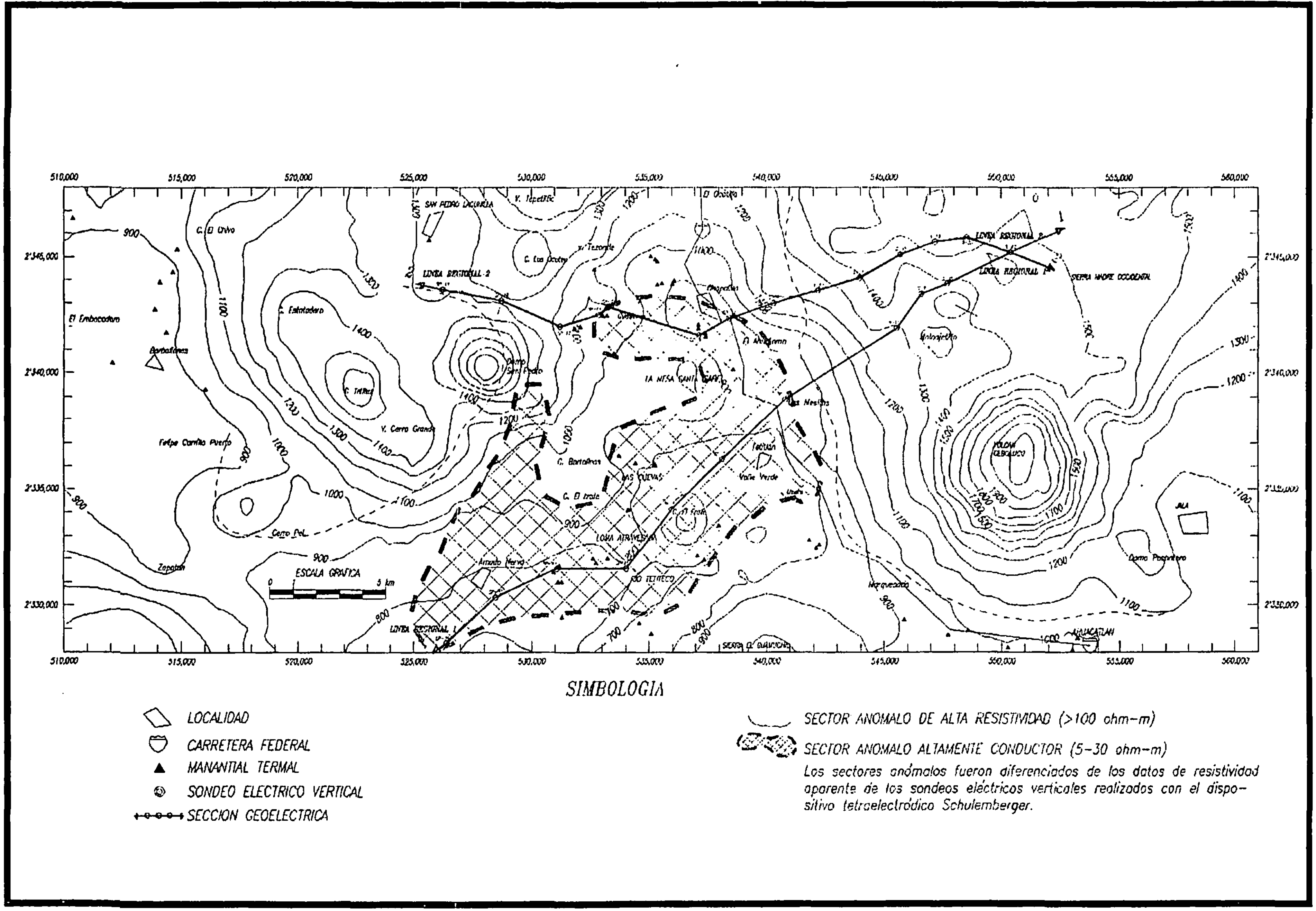
Objectives:

Granitic host rocks throughout the world have proven to be difficult to explore and develop because of their inherently low permeabilities. Exploration of these reservoirs is further hindered by the common presence of multiple hydrothermal events that make the normally utilized mineralogic indicators of permeability difficult to interpret. Despite these difficulties, granitic reservoirs have proven to be attractive targets in the Unites States (e.g. Coso, Steamboat Hot Springs, Roosevelt Hot Springs, The Geysers) and Guatemala.

The joint study we propose has two major objectives. First, it will directly assist CFE in their exploration program of Tres Virgenes. Secondly, it will provide DOE and the U. S. industry with important new data on the physical and chemical characteristics of granitic reservoirs. These data will assist in both the development of our existing fields and in the exploration of new systems where U. S. interests are involved (e.g. Meager Creek, British Columbia).

Program for 1994:

We propose to jointly collaborate on geologic and geochemical studies of Tres Virgenes. UURI will work with CFE geologists to determine the mineralogies of the altered rocks and their significance, develop a better understanding of the permeability structure of the reservoir, and characterize the chemical evolution and characteristics of the thermal system. CFE will provide samples of the rocks and fluids to UURI. We will conduct petrographic (thin section, X-ray diffraction, and SEM) and fluid inclusion analyses in support of the work being conducted by CFE. CFE and UURI will jointly prepare a report on the results of this work upon completion of the studies.



Los sectores anómalos fueron diferenciados de los datos de resistividad aparente de los sondeos eléctricos verticales realizados con el dispositivo tetraelectródico Schulemberger.

FIGURA 6.- INTEGRACION DE DATOS GEOELECTRICOS DE RESISTIVIDAD (SONDEOS ELECTRICOS VERTICALES)

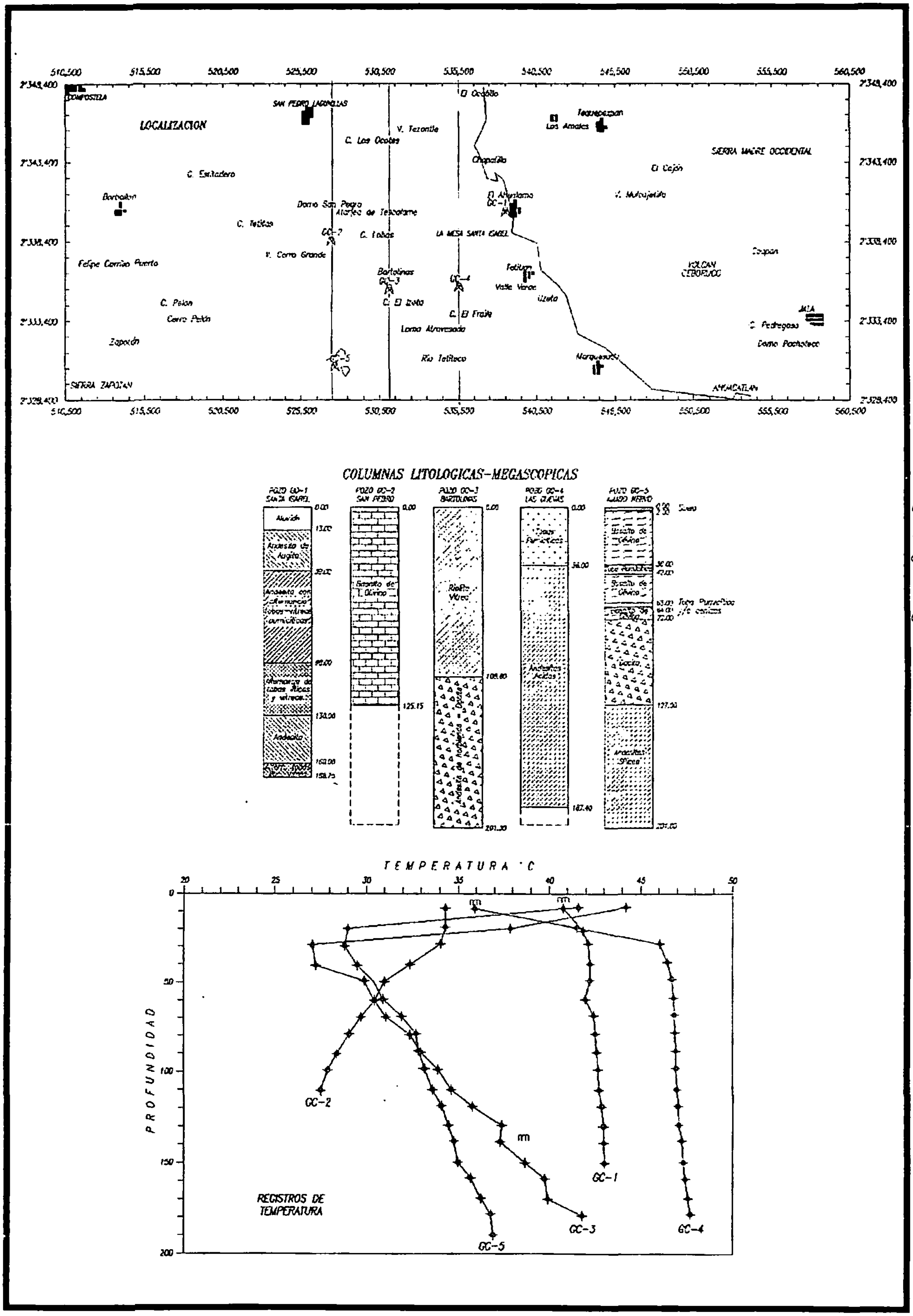


FIGURA 13.- CARACTERISTICAS GENERALES DE LOS POZOS DE GRADIENTE

GC-1	538.5 x 340.4
GC-2	527.5x 338.4
GC-3	531 x335.3
GC-4	535.5x 335.4
GC-5	527.5x 331,0

RELACION DE INFORMACION PARA EL PROYECTO CFE-DOE

EL CEBORUCO, NAY.

- PLANO DE ANOMALIA DE BOUGUER.

- CARACTERISTICAS GENERALES DEL LEVANTAMIENTO GRAVIMETRICO.

- CINTA MAGNETICA CON LA BASE DE DATOS MAGNETOTELURICOS, UTILIZANDO SOFTWARE GEOTOOLS, EN HARWARE SUN SPARC.

- COLUMNA LITOLOGICA (POZO CB-1).

- REGISTROS DE TEMPERATURA (POZO CB-1).

- ✓ GEOLOGIA REGIONAL DEL GRABEN TEPIC-IXTLAN, NAY. (INFORME 04/91).

- ✓ "PROYECTO GEOTERMICO EL CEBORUCO, NAY." -ESTADO ACTUAL DE LA EXPLORACION. (INFORME DEX/CEB/002/92.).

- INTEGRACION DE LOS ESTUDIOS GEOELECTRICOS DE RESISTIVIDAD EN "EL CEBORUCO, NAY.". (INFORME No. 02/92).

- INTERPRETACION CUALITATIVA DEL ESTUDIO MAGNETOTELURICO, REALIZADO EN EL -- CEBORUCO, NAY. (INFORME 04/93).

- ESTUDIO AEROMAGNETICO REGIONAL DEL SE DE NAYARIT. (EL CEBORUCO-SAN PEDRO-- TEPETILTIC). PROCESAMIENTO DIGITAL Y DESCRIPCION CUALITATIVA. (INFORME 15/91).

- ESTUDIO MAGNETOTELURICO DE LA REGION DEL CEBORUCO DOMO SAN PEDRO DEL ESTADO DE NAYARIT. INFORME FINAL (NOVIEMBRE - 1992).

90 MT sta in 1250 Km^2
$\sim$60 x 20 Km

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

March 28, 1991

Gerardo Garcia Estrado
Area de Geohidologia
Departmento de Exploacion
Gerencia de Prov. Geothermoelectrios
Comision Federal de Electricidad
Morelia, Michoacan, MEXICO
Fax (451) 447-35

Dear Gerardo:

Thank you for your letter of March 18 which arrived while I was on travel status for DOE. I am pleased to learn of the critical review of exploration strategies now underway at CFE, and to know that you are making good use of physical property data and numerical modeling techniques.

Your observations of the high noise/signal ratio for surface gravity and magnetic response of buried contrasts, in areas of high topographic relief, are consistent with my modeling results and experience in porphyry copper and geothermal exploration. These observations must, of course, consider the amount of topographic relief and the magnitude of the density or magnetic contrasts. While the density contrast is rather limited in volcanic areas (2.0 - 2.5 g/cm^3), the magnetic contrast could be much larger (0-3000 μcgs) and could include the additional effect of remanent magnetism. If the magnetic contrast of rocks forming the surface scarp is small (i.e. altered volcanic tuff) then the response from a greater contrast at depth, due to the same fault, may be recognized.

Gravity data in the Zunil area, Guatemala, are subject to extreme noise due to the high topographic relief (> 1000 m) which results in large terrain corrections (up to 13.6 mGal), errors in these corrections (± 3 mGAl ?), elevation errors, and improper Bouguer corrections. INDE must have done a good job in surveying and corrections, for the data do not appear to be unduly noisy, and some useful structural interpretations, which agree with the geology, have resulted. Of course at Zunil the topography, the geology and the gravity are all interrelated. A copy of our GRC paper is attached.

The gravity method may be of use if the topography is not too severe. The anomaly of a deeply buried density contrast has longer wavelength (lower frequency) than the effect of a topographic feature. Also the continuity of the structure, across several profiles of varying topography, may assist in the interpretation. Qualitative interpretation by correlation of high-frequency gravity anomalies with the topographic map, modeling and subtraction for the surface gravity anomaly, and perhaps filtering to remove high frequency, may all assist in the interpretation.

Surface magnetic measurements in magnetic volcanic areas are also subject to considerable noise, and to the effects of nearby terrain above and below the level of the instrument. The effect of a scarpin volcanic rocks may certainly dominate a deeper feature, and frequency filtering of ground magnetic data may not be as effective as for gravity anomalies. We prefer detailed aeromagnetic data! Ground magnetic data may be useful to compare the range of variability (mean & standard deviation and excursions) on each side of the scarp to help determine if the same rock unit is being traversed, and at the same stratigraphic level. This may not be conclusive, however. One additional comment: it is very hard to accurately establish the bulk magnetic properties of a volcanic unit, due to the variability of susceptibility and of remanent magnetism.

One other approach to determine if displacement has occurred across a scarp, is to compare short-dipole resistivity values on each side of the topographic feature.

I am pleased to hear that CFE may contract with UNAM for additional data interpretation of Los Azufres, especially if you and Oscar Campos may be involved. Please extend to Campos best regards from Mike Wright and myself. I would be pleased to comment on this study; or to assist in any other way that is possible.

I have had recent contact with D.D. Blackwell and D.S. Chapman, both of whom are expert in heat flow measurements in geothermal zones. Dr. Blackwell has had several grants from DOE-Geothermal Division. I have been the technical project monitor for DOE on some of these grants. Mike Wright also has considerable experience in heat flow studies. Addresses follow.

Dr. David D. Blackwell
Southern Methodist University
Department of Geological Sciences
Dallas, TX 75275
Tel: 214/692-2745

Dr. David S. Chapman
University of Utah
Department of Geology and Geophysics
505 Browning Building
Salt Lake City, UT 84112
Tel: 801/582-1073

Good Luck in your new and continuing geophysical studies. I will send some recent studies completed by UURI by mail. Best regards to your family and colleagues at CFE.

Sincerely,

Howard P. Ross

Howard P. Ross/pfs
Section Head/Applied Geophysics

encl.

Morelia, Mich., March 18 th , 1991.

Gerardo García Estrada
Area de Geohidrología
Departamento de Exploración
Gerencia de Proy. Geothermoeléctricos
Comisión Federal de Electricidad
FAX: (451) 447-35

Howard Ross
University of Utah Research Institute
391 Chipeta Way Suite C
Salt Lake City
Utah, U.S.A.
FAX: (801) 524-3453

Dear Ross:

Finally the Comisión Federal de Electricidad has initiated a critical review of the exploratory strategies used for the last ten years, specially focused to the processing and interpretation of geophysical data. I have been working some 2D models in order to estimate the magnitude of gravity and magnetic anomalies related to buried density or susceptibility contrasts. What I have found is that using "reasonable" values for the parameters (considering we are working in a volcanic zone), the topographic efects are 5 to 7 times higer than those related to the buried contrast.

This result is very interesting for us because we are analysing the possibility to use ground based potential fields in order to confirm whether a topographic scarp is or not a consequence of a fault. The conslusion is that although the buried contrast is perfectly detectable from an instrumental point of view, the presence of the scarp makes necessary to do a careful model of the problem before arriving to any conslusion, and discourages a qualitative-only approach. Inspite the knowledge won, problems are still present, because the ratio noise (scarp)/ signal (buried contrast) is inadecuate.

I would like to know your opinion, specially because Joseph More told me you were working in Guatemala, and you have found some negative result related to fault detection.

The CFE is going to contract the University of Mexico (UNAM) in order to make a joint CFE-UNAM reinterpretation of available geophysical and geological data at Los Azufres field. Probably this contract will include the interpretation of the aeromagnetic data of the DOE-CFE aggreement. Surely I will participate in this task, with the university's team were our former colleage Campos is now working with.

I would like to have your help and valuable comments related to this job, and of course the agreement for your inclusion in the paper that could result, what is very probably bacause this is the first aim of academic institutions. With your participation and your experience, I am sure, the results could be more realistic. I will give you more details after the signation of the contract.

Thank you for the papers you have sent us related to dipole-dipole technique. Surely, I will be in contact with you more frecuently, in order to comment the results of this new stage of exploratory job at CFE, promote by Dr. Luis Quijano .

Do you or sombody at UURI could provide me the address of some researcher working with heat flow measurements in geothermal zones?, may be D.D.Blakwell of Methodist University at Texas, or D.S. Chapman or J. Coms, for example?.

Please give my regards to your wife and the same for your colleages at UURI.

Gerardo Héctor García Estrada

The bipole-dipole array (also called total field, roving dipole and other names) has also been used to advantage in deep mineral and geothermal exploration by UURI, the U. S. Geological Survey, and many mineral companies. This array is used in earlier reconnaissance stage exploration, because one transmitter dipole of 610 m length can be used to obtain preliminary resistivity data over an area of 5-15 sq km. There is also considerable flexibility in locating the perpendicular receiving dipoles so as to avoid rough topography (such as reading across hills, rivers, etc.), and in making good use of road and trail access. The derived apparent resistivity values are influenced by the earth resistivity in the vicinity of the transmitting dipole (referred to as the transmitter overprint phenomena) so it is necessary to overlap coverage from different transmitter sites. This array results in an aerial distribution of resistivity data and is useful for locating anomalies, but does not provide information on the depth or specific geometry of the source body. Thus it should be followed up with dipole-dipole or pole-dipole data.

b) Distance between current electrodes. The fundamental survey parameter is the dipole length, a, which governs both the lateral resolution and the effective depth of exploration (the greater the distance between the current electrodes, the greater the current penetration). Typical transmitting dipole lengths used in the dipole-dipole array for geothermal and mineral exploration are 152 m (500 ft), 305 m (1000 ft), and occasionally 457 m (1500 ft). Dipole lengths greater than 457 m are not often used due to the increased influence of bodies lateral to the profile, and due to the reduced resolution. Transmitting dipole lengths of 500 to 1000 m are often used in the bipole-dipole array.

The maximum practical distance between current and potential electrodes is generally regarded to be 7 or 8 times the dipole length, because of lateral effects, completeness of near surface readings along the line, and signal/noise considerations. This generally results in an adequate current distribution to depths of 2 to 3 times the dipole length, depending upon the resistivity values and structure. With careful numerical modeling of dipole-dipole data the resistivity model can be reasonably accurate to depths of 2a to 2.5a, i.e. depths of 610 to 760 m for a 305 m dipole length and readings to separations of n=7 or 8.

Although these implied depths of exploration seem quite limiting for geothermal reservoir delineation, our experience in Basin and Range and volcanic geothermal systems suggests that leakage, alteration, and structural control to these depths somewhat above the actual geothermal reservoir are very useful information in mapping the deeper reservoir and in selecting drilling targets.

c) Dipole separations (n=1, 2, etc.). These values refer to the minimum distance between a transmitter electrode and receiver electrode. There may be some difference between US and some European conventions in labeling these separations. In the US convention, the first separation read, n=1, results from a one dipole length interval between the nearest transmitting electrode and the first receiving electrode. Similarly the seventh separation (n=7) would refer to 7a (7 x 305m = 2135m for a=305 m). Illustrations will follow in the mail.

d) Power Capacity of the resistivity equipment. There is a fairly large range of transmitter power available for purchase, depending upon depth of exploration desired, and expected apparent resistivity values (both of which dictate the signal strength) and the type of receivers to be used, some of which may include microprocessors for signal stacking, averaging, and other noise reduction techniques. Several tradeoffs should be considered in the purchase of a resistivity exploration system: power output to overcome geologic and other noise and to obtain adequate depth of exploration; equipment portability and reliability- the higher power output systems require larger motor generators, trailers or dedicated trucks, and perhaps specialized helicopter support; and initial and upkeep costs.

UURI has completed numerous surveys for geothermal and mineral exploration to depths of 700 m using the Elliot Time Domain IP Transmitter, Model 15 A which has the following characteristics:

Input power: 120 volt 400 Hz, single phase at 1800 VA
Output power: 1500 watts
Output voltage: 200 to 3000 volts in 12 selected steps
Output current: 5 Amps maximum
Weight, in case: 45 lbs (20 kg)
Motor generator weight: (about 100 lbs -45 kg)

A more powerful system often used for Induced Polarization surveys (which require a higher signal to noise ratio) and for deeper resistivity exploration has these characteristics:

Input power: 208/120 volt 400 Hz three phase at 5500 VA
Output power: 4500 watts
Output voltage: 450 to 3000 volts in 7 steps
Output current: 10 amps maximum
Weight, in case: 70 lbs (32 kg)
Motor generator weight: (about 240 lbs -109 kg)

One US firm markets a high power transmitter, 28KVA (20 amps at 1000 volts) powered by a 350 kg motor generator that must be permanently skid mounted or trailer mounted. This equipment is used primarily for CSAMT and IP surveys for deep exploration.

We would suggest that an output power of 1500 to 4500 watts would be adequate for most geothermal exploration needs, if adequate efforts are made in electrode preparation and data collecting.

Certainly a great deal more could be said about each of the subjects which you noted. We hope that the above discussion and the materials we are mailing separately will be of some help for now. Please do not hesitate to contact us for further clarification or discussion of these and other topics. Although our schedules are unpredictable, we should be able to respond more promptly in the future.

Best Regards,

Phillip M. Wright
Technical Vice President

Howard Ross
Howard P. Ross
Section Head/Applied Geophysics

~~15-2-88~~ (9-9-2300) Acuf e

COMISION FEDERAL DE ELECTRICIDAD

COORDINADORA EJECUTIVA LOS AZUFRES

MELCHOR OCAMPO Pte. 35 Tels. 403-52 409-44 405-99 418-81 61100 CD. HIDALGO, MICH.

DEPARTAMENTO DE ABASTECIMIENTOS
OFICIO No. CAGG/0121/88.

Ciudad Hidalgo Mich., Marzo 3 de 1988.

Country Code = 52
mexico
011-52-

Antonio Razo [8-3 pm, 6-7:30pm]
office: (451) 44940
home: (451) 47459

ING. JAIME ORTIZ RAMIREZ
SUPERINTENDENTE GENERAL DE ESTUDIOS
PRESENTE:

Ing. Gerardo García Estrada
Comision Federal de Electricidad
Departamento de Exploración
Gerencia de Proyectos ~~Geotermoeléctricos~~
Geotermoeléctricos - Morelia, Mich.
P.O. Box 248
Calexico, CA 92231

e --
1988, donde no: ca -
que D.O.E. uti: es
te equipo ya pu idad
de México; por n -
UURI... directa

Agencia Aduanal a -
Tels: 784-41-02 --

dor de la Aduan tra
arribo de este l -

el televisor So que
la posibilidad ea

internación al --

solicitado, que-
do de Usted.

verify: Insu[illegible]
: shipping [illegible]
: packing lists
: US C[illegible]
: [illegible]
: Dale Green [illegible]

ATENTAMENTE

ING. CARLOS A. GARCIA GUTIERREZ
JEFE DEL DEPTO. DE ABASTECIMIENTOS

c.c.p.- Ing. Ramón Reyes Suárez.- Coordinador Ejecutivo. Presente.
c.c.p.- Ing. Antonio Razo Montiel.- Jefe del Depto. de Exploración.- Morelia Mich.,
c.c.p.- C.P. Alfonso Tello Garfías.- Administrador General. Presente.
c.c.p.- Ing. Rogelio Huitrón Esquivel.- Superintendente de Geología.- Presente.
c.c.p.- Ing. J. Francisco Arellano G.- Jefe de la Oficina de Geofísica.- Morelia Mich.,
c.c.p.- Expediente.
c.c.p.- Consecutivo.

CAGG/emr.

- Tape [illegible] Mexico [illegible] → [illegible]
- Airline Reserv?
- UURI labels?
- F[illegible] ←

Mag. Equipment Bill of Lading No:
AA 001-06189831

APPENDIX A

MOST IMPORTANT PERSONNEL OF COMISION FEDERAL DE ELECTRICIDAD (CFE) MET BY THE U. S. DELEGATION DURING THIS TRIP

GERENCIA DE PROYECTOS GEOTERMOELECTRICOS
(Managed of Geothermal-Electric Projects)
Ing. Hector Alonso Espinosa, Gerente
Ing. Arturo Gonzalez Salazar, Subgerente de Estudios Geotermicos

Address for all Morelia offices:
Gerencia de Proyectos Geotermoelectricos de CFE
Apto. Postal 31-C
Morelia, Michoacan 58290
Mexico

DEPARTAMENTO DE EXPLORACIONES
(Department of Exploration)
Ing. Antonio Razo Montiel, Jefe

Oficina de Geologia
(ffice of Geology)
Ing. Saul Venegas Salgado, Jefe
Ing. Cesar Viggiano Guerra (petrography, mineralogy)
Ing. A. Arellano

Oficina de Geofisica
(Office of Geophysics)
Ing. Hector Lira, Jefe
Ing. Jose Francisco Arellano A.
@ Ing. Gutierriz Negrin
Ing. Oscar Campos E.

Oficina de Geoquimica
(Office of Geochemistry)
Fis. Jose Luis Quijano Leon, Jefe
Ing. Julio Cesar Vieggano

DEPARTAMENTO DE EVALUACION Y YACIMIENTOS
(Department of Evaluation and Reservoirs)
Ing. Rafael Molinar Cesena, Jefe

Oficina de Pruebas y Modelos de Simulacion
(Office of Testing and Modeling)
Ing. Jose Luis Sanabria Martinez, Jefe
Dr. Cesar Suarez Arriaga (modeling LOs Azufres)
Ing. Miguel Angel Ayuso O. (modeling Cerro Prieto)
Ing. Pedro Sanchez
Ing. H. Gutierrez

Oficina de Reinyeccion
(Office of Reinjection)
Ing. Alfonso Aragon Aguilar, Jefe

COORDINADORA EJECUTIVA DE LOS AZUFRES
(Office of Executive Coordinator of Los Azufres)
Ing. Ramon Reyes Suarez, Coordinador Ejecutivo

Superintendencia General de Estudios
(Office of General Superintendent of Studies)
Ing. Jaime Ortiz, Superintendente General

Superintendencia de Geologia
(Office of Superintendent of Geology)
Ing. Rogelio Huitron Esquivel, Superintendente
Ing. Antonio Abad (surface geology)
Ing. Marco Alfonso Gonzalez (subsurface geology)

Superintendencia de Geofisica
(Office of Superintendent of Geophysics)

Superintendencia de Geoquimica
(Office of Superintendent of Geochemistry)
Ing. Mario Gallardo, Superintendente

Superintendencia de Ingenieria de Yacimientos
(Office of Superintendent ^f Reservoir Engineering)
Ing. Carlos Miranda

Disposition:

To: S.PRESTWICH (DOE1020)
To: P.WRIGHT (DOE4433)
To: J.RENNER (DOE4437)
From: J.RENNER (DOE4437) Delivered: Tue 29-Sep-87 9:21 EDT Sys 164 (3)
Subject: salton sea panel
Mail Id: IPM-164-870929-084250586
Acknowledgment Sent

talked to Treusdell late yesterday. he is willing to serve on the panel. he sug gested the----------
he suggested the possibility of a breakfast meeting. I have not yet heard from Mohinder-------------
Mohinder as to whether he has permission for Unocal to participate.

Disposition: d

To: DOE4433
From: S.STIGER (DOE4467) Delivered: Tue 29-Sep-87 9:29 EDT Sys 164 (0)
Subject: Acknowledgment of: SALTON SEA PANEL
Original Mail Id: IPM-164-870923-125150756
Received: Tue 29-Sep-87 9:29 (Explicit)
Mail Id: IPM-164-870929-085470028

Disposition: d

To: S PRESTWICH (DOE1020)

CFE TELEPHONE AND TELEX NUMBERS (UPDATED AS OF 9/22/87)

MEXICO: Country Code: 52

CD.HIDALGO:	City Code: 725
CUERNAVACA:	City Code: 731
MEXICALI:	City Code: 65
MORELIA:	City Code: 451

CFE - SUPERINTENDENCIA GENERAL DE LOS AZUFRES
(One has to call CIUDAD HIDALGO, Michoacan, where one is connected via radio to the field)

Switchboard (?): 4-0352; 4-0944; 4-0599

CFE - COORDINADORA EJECUTIVA DE CERRO PRIETO, MEXICALI, B.C.

Switchboard: 53-6801 TELEX: CECM 56702

Manon:	53-5142
Bermejo:	53-5948

CFE - GERENCIA DE PROYECTOS GEOTERMOELECTRICOS, MORELIA, MICH.

Switchboard for the Alejandro Volta offices : 4-8048 and 4-8050

TELEX: 69623 PGTEME

Alonso:	4-4606; 4-4695
Gonzalez:	4-5970
Hiriart:	4-3970
Molinar:	4-3649
Quijano:	4-3023
Razo:	4-4940
Sanabria:	4-3649
Benegas:	4-3811

4-4735 Soñia Aileri

INSTITUTO DE INVESTIGACIONES ELECTRICAS, CUERNAVACA, MORELOS

Switchboard: 4-3811 TELEX: 173380 INIEME

Iglesias:	Extension 3210
Nieva:	4-1433

LUISQ.CFE

13 September 1990

Ing. Luis Quijano
Comision Federal de Electricidad
Departamento de Exploracion
Gerencia de Proyectos Geotermoelectricos
Alejandro Volta No. 655
Colonia las Camelinas
Morelia, Michoacan, MEXICO

Dear Luis:

Thank you for your telefax of 17 August 1990 regarding information relating to the dipole-dipole resistivity method. Please forgive our late reply, but we have been away attending the 1990 International Geothermal Energy Symposium, and on vacation. We are pleased to learn that you are considering other electrical resistivity arrays for CFE geothermal exploration, and will attempt to answer your questions. Additional information will follow this FAX by mail.

a) Best type of array. Perhaps more than 20 different electrode arrays have been used in various types of exploration, and numerous technical papers have been written to compare the merits of the various arrays. The Schlumberger array (Vertical Electrical Sounding, or VES) is perhaps the most familiar on a worldwide basis, and is probably the best array for layered (one-dimensional) geology. The method requires a large current electrode separation for deep exploration, and this means more field effort (and cost) and greater probability of crossing geologic changes which would invalidate a layered-earth interpretation. Most mineral deposits and geothermal systems occur in a complex two- or three-dimensional geology (and resistivity structure) which limits the use of the VES array.

Most mining companies have selected the in-line dipole-dipole or pole-dipole array for deep (100 to 1000 m) mineral exploration. The pole-dipole array results in greater current penetration to depth, but poorer spatial resolution for anomalous bodies. The in-line geometry is useful for orienting lines perpendicular to geologic structures, contrasts, and topography, and for minimizing the effects of powerlines, pipelines, etc.
Both the pole-dipole and dipole-dipole arrays record

information about lateral and vertical resistivity distributions. Several computer techniques have been developed for the numerical modeling of dipole-dipole data, including modeling the effects of topography. We feel that the dipole-dipole method offers the best combination of resolution, efficent field operation and interpretation, and still has acceptable depth penetration. Several oil companies have made use of the method in conducting resistivity/ induced polarization surveys for deep petroleum exploration, and geothermal explorationists throughout the world also seem to favor the in-line dipole-dipole method, but not to the complete exclusion of other arrays.

The bipole-dipole array (also called total field, roving dipole and other names) has also been used to advantage in deep mineral and geothermal exploration by UURI, the U. S. Geological Survey, and many mineral companies. This array is used in earlier reconnaissance stage exploration, because one transmitter dipole of 610 m length can be used to obtain preliminary resistivity data over an area of 5-15 sq km. There is also considerable flexibility in locating the perpendicular receiving dipoles so as to avoid rough topography (such as reading across hills, rivers, etc.), and in making good use of road and trail access. The derived apparent resistivity values are influenced by the earth resistivity in the vicinity of the transmitting dipole (referred to as the transmitter overprint phenomena) so it is necessary to overlap coverage from different transmitter sites. This array results in an aerial distribution of resistivity data and is useful for locating anomalies, but does not provide information on the depth or specific geometry of the source body. Thus it should be followed up with dipole-dipole or pole-dipole data.

b) Distance between current electrodes. The fundamental survey parameter is the dipole length, a, which governs both the lateral resolution and the effective depth of exploration (the greater the distance between the current electrodes, the greater the current penetration). Typical transmitting dipole lengths used in the dipole-dipole array for geothermal and mineral exploration are 152 m (500 ft), 305 m (1000 ft), and occassionally 457 m (1500 ft). Dipole lengths greater than 457 m are not often used due to the increased influence of bodies lateral to the profile, and due to the reduced resolution. Transmitting dipole lengths of 500 to 1000 m are often used in the bipole-depole array.

The maximum practical distance between current and potential electrodes is generally regarded to be 7 or 8 times the dipole length, because of lateral effects, completness of near surface readings along the line, and signal/noise considerations. This generally results in an adequate current distribution to depths of 2 to 3 times the dipole length, depending upon the resistivity values and structure. With careful numerical modeing of dipole-dipole data the resistivity model can be reasonably accurate to depths of 2a to 2.5a, i.e. depths of 610 to 760 m for a 305 m dipole length and readings to separations of n=7 or 8.

Although these implied depths of exploration seem quite limiting for geothermal reservoir delineation, our experience in Basin and Range and volcanic geothermal systems suggests that leakage, alteration, and structural control to these depths somewhat above the actual geothermal reservoir are very useful information in mapping the deeper reservoir and in selecting drilling targets.

c) Dipole separations (n=1, 2, etc.). These values refer to the minimum distance between a transmitter electrode and receiver electrode. There may be some difference between US and some European conventions in labeling these separations. In the US convention, the first separation read, n=1, results from a one dipole length interval between the nearest transmitting electrode and the first receiving electrode. Similarily the seventh separation (n=7) would refer to 7a (7 x 305m = 2135m for a=305 m). Illustrations will follow in the mail.

d) Power Capacity of the resistivity equipment. There is a fairly large range of transmitter power available for purchase, depending upon depth of exploration desired, and expected apparent resistivity values (both of which dictate the signal strength) and the type of receivers to be used, some of which may include microprocessors for signal stacking, averaging, and other noise reduction techniques. Several tradeoffs should be considered in the purchase of a resistivity exploration system: power output to overcome geologic and other noise and to obtain adequate depth of exploration; equipment portability and reliability- the higher power output systems require larger motor generators, trailers or dedicated trucks, and perhaps specialized helicopter support; and initial and upkeep costs.

UURI has completed numerous surveys for geothermal and mineral exploration to depths of 700 m using the Elliot Time Domain IP Transmitter, Model 15 A which has the following characteristics:

Input power: 120 volt 400 Hz, single phase at 1800 VA
Output power: 1500 watts
Output voltage: 200 to 3000 volts in 12 selected steps
Outzput current: 5 Amps maximum
Weight, in case: 45 lbs (20 kg)
Motor generator weight: (about 100 lbs -45 kg)

A more powerful system often used for Induced Polarization surveys (which require a higher signal to noise ratio) and for deeper resistivity exploration has these characteristics:

Input power: 208/120 volt 400 Hz three phase at 5500 VA
Outout power: 4500 watts
Output voltage: 450 to 3000 volts in 7 steps
Output current: 10 amps maximum
Weight, in case: 70 lbs (32 kg)
Motor generator weight: (about 240 lbs -109 kg)

One US firm markets a high power transmitter, 28KVA (20 amps at 1000 volts) powered by a 350 kg motor generator that must be permanently skid mounted or trailer mounted. This equipment is used primarily for CSAMT and IP surveys for deep exploration.

We would suggest that an output power of 1500 to 4500 watts would be adequate for most geothermal exploratioh needs, if adequate efforts are made in electrode preparation and data collecting.

Certainly a great deal more could be said about each of the subjects which you noted. We hope that the above discussion and the materials we are mailing separately will be of some help for now. Please do not hesitate to contact us for further clarification or discussion of these and other topics. Although our scheduleds are unpredictable, we should be able to respond more promptly in the future.

Best Regards,

Phillip M. Wright
Technical Vice President

Howard P. Ross
Section Head/Applied Geophysics

HR

MEXPRI01.DOS

MAIL DOE1021 AR 'MEXICAN PRIORITIES'

MEMO TO: PAUL KRUGER

FROM: MIKE WRIGHT

SUBJECT: PRIORITIES FOR MEXICAN WORK

November 7, 1988

The only comment we have on your list of proposed projects concerns the UURI tracer test. We have discussed doing this test with the Los Azufres people, but if either La Primavera or Los Humeros sites would be preferred for some reason, we would change the location.

Priorities for the work we have proposed are:

A.1.a Priority = 1. No CFE co-investigators assigned yet.

A.1.b Priority = 1. No CFE co-investigators assigned yet.

A.1.c Priority = 3.

A.1.d Priority = 2. No CFE co-investigators assigned yet.

B.1.a Priority = 1. Same CFE co-investigators.

B.3.h Priority = 1. No CFE co-investigators assigned yet; We suggest J. Ortiz and L. Quijano.

C.1.a Priority = 3.

C.1.b Priority = 3.

C.1.g Priority = 3.

C.1.h Priority = 3.

.S

.END

To: Distribution
Subject: Third Draft of Proposed Joint Studies
Date: 26 October 1988

Listed below is the current version (as of 10/26/88) of the list of potential joint studies for which proposal outlines have been compiled. Please review and send me any changes concerning field sites, title, DOE investigators, and priorities.

Requested priorities can be chosen by the following criteria:

0 = no priority: no joint study proposed by a DOE participant.
1 = high priority: can and should be started in FY89 with available DOE funding under existing programs.
2 = medium priority: can be started in FY89 with available DOE funding, but requires extensive equipment or travel or is of lesser importance for FY89.
3 = low priority: of interest, but cannot be carried out in FY89 with available DOE funding.

Please also indicate if CFE co-investigators have already been identified for each joint study. The names will be included in the draft we send to CFE to facilitate matching of the two lists.

Distribution:
mail copies to V.Roberts (EPRI) A.Truesdell (USGS)
E-mail copies to
M.Wright (UURI)
M.Lippmann (LBL)
P.Kruger (SGP)
J.Dunn (Sandia)
H.Murphy (LANL)
J.Renner (INEL)
L.Kukacka (BNL)
cc: T.Mock, D.Lombard, J.Rannels, M.Reed (DOE Hq)

DOE-CFE GEOTHERMAL AGREEMENT
RENEWAL PROGRAM
SUMMARY of PROPOSED JOINT STUDIES
(Third Draft pk:26Oct88)

	Requested Priority
A. Los Humeros	
1. Geosciences	
a) Aeromagnetic Surveys of Los Humeros M.Wright + H.Ross (UURI)	(?) 1
b) Geological and Geochemical Studies J.Moore + M.Adams (UURI) + A.Truesdell (USGS)	(?) 1
c) Satellite Imagery Interpretation M.Wright + L.Allison + D.Ramsey (UURI)	(?) 3
d) Electrical Geophysics M.Wright (UURI)	(?) 2
2. Drilling	
a) Stimulation of Granitic Rock ? (LANL)	3
b) Air Drilling	0
3. Reservoir Engineering	
a) Flow and Transport Simulation at Los Humeros J.Renner + J.Miller (INEL)	1
b) Cooldown Potential with Reinjection Recharge P.Kruger (SGP)	1
c) Chemical Reservoir Engineering P.Kruger (SGP)	1
d) Reservoir Modeling	0
e) Well Testing	0
f) Reinjection	0
B. Los Azufres	
1. Geosciences	
a) Geologic and Geochemical Studies J.Moore + M.Adams (UURI) + A.Truesdell (USGS)	(?) 1
b) Microseismic Studies for Field Exploration E.Majer (LBL)	(?)
c) Subsidence	0
2. Drilling	
a) Air and Air-Fluid Drilling	0
b) Well Stimulation ? (LANL)	3
c) Well Completion	0
d) Chemical Analysis for Well Completion	0

D. Cerro Prieto
- 2. Drilling
  - a) Gas Fracturing for Stimulating Clogged Wells (?)
    T.Chu (Sandia)
  - b) Downhole Testing of Geothermal Well Cements under High Temperature Flowing Brine Conditions (?)
    L.Kukacka (BNL)
- 3. Reservoir Engineering
  - a) Reservoir Response to New Central Power Plants with Interference and Injection Well Tests 3
    S.Benson (LBL)
  - b) Study of Reservoir Processes with Changing Fluid Composition 2
    M.Lippmann (LBL)
  - c) Field Modeling 1
    M.Lippmann (LBL)
- 4. Generation
  - a) Field Testing of Thermally Conductive Polymer Composite Heat Exchanger Tubing (?)
    L.Kukacka (BNL)

3. Reservoir Engineering
a) Field Studies at 50-MW and 5-MW Units with Interference and Injection Well Tests 3
S.Benson (LBL)
b) Study of Reservoir Processes with Changing Fluid Composition 2
K.Pruess (LBL) + A.Truesdell (USGS)
c) Heat Extraction by Reinjection Recharge 1
P.Kruger (SGP)
d) Chemical Reservoir Engineering at Unit Wells 1
P.Kruger (SGP)
e) Modeling of the Los Azufres Field 2
K.Pruess (LBL)
f) Field Reactive Tracer Experiments 1
(?) (LANL)
g) Microseismic Evaluation of Fractured Reservoirs 2
(?) (LANL)
h) Tracer Testing (added post DOE-CFE meeting) (?) 1
M.Adams + J.Moore + M.Wright (UURI)

4. Generation
a) Heat Cycles-Advanced Heat Rejection 0
(?) (INEL)
b) Application of EPRI Reboiler Technology to Control Noncondensable Gases 0
V.Roberts (EPRI)

C. La Primavera

1. Geosciences
a) Aeromagnetic Surveys of La Primavera (?) 3
M.Wright + H.Ross (UURI)
b) Geologic and Geochemical Studies (?) 3
J.Moore + M.Adams (UURI) + A.Truesdell (USGS)
c) Magnetotelluric Studies at La Primavera (?)
N.Goldstein (LBL)
d) Petrophysical Measurements 0
e) Gravimetric Survey 0
f) Isotopic Studies 0
g) Satellite Imagery Interpretation (?) 3
M.Wright + L.Allison + D.Ramsey (UURI)
h) Electrical Geophysics (?) 3
M.Wright (UURI)

2. Drilling
a) Evaluation of Lost Circulation Characterization and Control Methods (?)
D.Glowka + G.Loeppke (Sandia)
b) Air and Air-Fluid Drilling 0

3. Reservoir Engineering
a) Chemical Reservoir Engineering 1
P.Kruger (SGP)
b) Cooldown Potential with Reinjection Recharge 1
P.Kruger (SGP)
c) Field Reactive Tracer Experiments 1
? (LANL)

SUBJECT: Postponement of DOE-CFE Meeting Scheduled for April 25-26, 1995

The above meeting should be postponed for several reasons:

1) ESRI received a request for detailed numerical modeling of two magnetotelluric (MT) lines on March 8. The request comes much too late, in view of ongoing work and personnel commitments, to respond to before the scheduled meeting. CFE geophysicists have not been able to come to ESRI to work with Dr. Wannamaker, as originally planned.

2) CFE has not been able to send scientists up to ESRI to work with the remote sensing/GIS equipment, an important part of the agreement. ESRI has undertaken data processing of the agreed upon imagery, but additional work, preferably with CFE participation, needs to be done.

3) ESRI requires more time to get a complete translation of the final report of the Ceboruco geothermal study, before being able to offer comments on the CFE exploration strategy - a potentially sensitive item.

4) ESRI scientists have major time conflicts with the scheduled meeting time.

5) We understand the CFE scientists do not want a meeting at the scheduled time. We also understand (from a third party) that Gerardo Hiriart, CFE, will not be able to attend the meeting.

In view of the considerable cost and time involved it seems desirable to hold the meeting after more meaningful interaction between CFE scientists and their U.S. counterparts, at some later date.

CFE report translation.

Charge 5-25628

Priority

1 5. PERFORACION DE POZOS EXPLOR ~

p. 16, 17, 18, 19, 20 (5 pgs) ✓

2 3 - ESTUDIOS GEOFISICOS

p. 9, 10, 11, 12 (4 pgs)

3 6- EVALUACION GEOTERMICA

p. 21, 22, 23, 24, 25, 26, 27, 28 (8 pgs)

4 7- CONCLUSIONES

p. 29, 30, 31 (2.2 pgs.)

5 RESOMEN (1 pg.)

6 2.5 Modelo Geologico (1 pg.)

Sandia Acct.
for CFE

5-25628
Geothermal Remote
Sensing

[redacted]

[redacted]

April 7, '95

Beth —

I will be in the field for two weeks, returning on April 24.

If you have any spare time for translation, please undertake this report, in the priority order I have indicated.

Priorities 1 and 2, about 9 pages are most important to me. I can read most of the geology/geophysics words but, the rest of the text is difficult.

Thanks in advance,

Howard

— Charge 5-25626 Account —

Howard,

I've been out this week due to surgery I had on Tuesday. I'll be home bound for 2-3 weeks beginning 4/24. I finished the first two priorities listed. If you need more and do not have a dead-line in the near future I could probably work on a few pages at a time while recupping.

I hope this all makes sense to you.

Beth

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
ENVIRONMENTAL STUDIES LABORATORY
391 CHIPETA WAY, SUITE D
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE: 801-524-3460

5.- Drilling of Ex

Pages 16-20

PERFORACION DE POZOS EXPLORATORIOS

Priority #1

The result … the location of 3 wells 2000 m
deep (Figure 3.9) … many thermal anomalies related
to a geothermal … the generation of electrical
energy.

Well CB- … he Ceboruco volcano at the
following coordi … = 1130 msnm, within the
Marquesado ejid

Well CB-2.- Drilling took place 18 km. west of CB-1, at the following coordinates: X = 529,850 Y = 2'333,400 and Z = 850 msnm, within the Amado Nervo ejido, San Pedro Lagunillas municipality.

Well CB-3,- Drilling took place 3.4 km northeast of the San Pedro Central Dome and 9 km north-northeast of the CB-2 well, at the following coordinates: X = 530,950, Y = 2'342,650 and Z = 1220 msnm, within the San Pedro Lagunillas municipality.

5.1.- Technical Reasoning for Site Selection

The reasoning behind the techniques used to select the drilling sites were geochemical, geological and geophysical. In the case of site CB-1, it was determining the existence of a geothermal deposit associated with the volcano Ceboruco. In the geochemical studies, gases were sampled and analyzed from the fumaroles and the hot surface of the craters of the Ceboruco volcanic system (five cones), with maximum temperatures of 92 C, resulting from spewing carbon dioxide, sulfuric acid and hydrogen in quantities comparable to those found in geothermal wells of high entalpy.

With the geothermometric application of the gaseous phase it was calculated that bottom temperatures were on the order of 267 C; analysis of the mercury showed percentages higher than any other geothermal zone of the country.

The regional and detailed geologic studies conclude that the volcanic structure must be connected to a magma chamber that is scarcely in the cooling stage, since the last eruption was historic (1870 - 1875) and related to an important developing tectonic area.

Based on the geophysical surveying with the MT method, the site was recommended as a base, the supposition being that the type and value of resistivity detected, could be associated with the geothermal deposit; the gravimetric and aeromagnetic studies yielded as results that the minimal anomalies present are related to the area of geothermal interest.

For the well site CB-2, the geochemical arguments are in the analysis of the thermal manifestations of the Tetitlan-Valle Verde and Amado Nervo valleys. Constituted or formed by springs with maximum temperatures of 48 C. Furthermore, the elements detected suggest that they are indicators of geothermal activity. The estimated temperatures with the K-Mg geothermometer vary between 53 to 68 C, however, this estimation is restricted by the secondary vegetation at the springs.

The geologic studies are based on the volcanologic development of the area where a series of domes have been located composed of dacite, rhyolite, and andesite beginning at the lower Quaternery (1.7 Ma). Such structures are found to be in a NW-SE alignment in a weak zone lending itself for the formation of the domes.

The geophysical (geoelectric and gravimetric) arguments supported the CB-2 site since the intermediate conductor shows minimum resistivity values in this zone that could be related to high geothermal saturation or alteration, the qualitative analysis on the Bouguer anomaly detected a minimum gravimetric zone that is interpreted as a graben or semigraben oriented NW-SE.

For the well site CB-3 the geochemical studies performed at the Guasimas manifestation with 31 C, and the closest to the site, indicates concentrations of boron, sulfates, and chloride as indicators of geothermal activity.

The geologic studies support the area due to the existence of a dome complex with alkaline traces, dacite, and rhyolite 0.850 to 0.790 Ma, for San Pedro and up to 0.101 Ma, for the Los Ocotes dome. Oriented NW-SE and N-S on a weak strip of land, associated with (lye or bleach mugearitic, as you would find SMO basal andesite)?

The electrical geophysical studies resulted in a very important correlation between the anomalies of low resistivity with possible fracture or heat zones. Furthermore, the Bouguer regional anomaly presents minimum gravimetry in the area of the San Pedro domes, that could be related to a depression where the recent domes were located.

5.2.- OBJECTIVES

Well CB-1

a) Determine the presence of a geothermal deposit associated with the Ceboruco Volcano.

b) Locate the deposit in the basal andesite unit of the Sierra Madre Occidental (West), Oligocene-Miocene, that due to intense compressed deformation is folded, faulted, and fractured producing good secondary permeability, that constitutes an aquifer with a thickness of 600 -700 m, favorable for possible exploration of the deposit.

c) Prove the proposed geologic model.

d) Recognize the physical characteristics of magnetic susceptibility, density and conductivity in the core materials extracted during drilling as well as all other data.

e) Establish the distribution of the hydrothermal mineralogy both in its paragenesis as well as its relationship to vulcanism of Ceboruco.

f) Determine what rock characteristics control the anomalies of low resistivity obtained through the magnetoteluric method whose qualitative values lower than 10 Ohm.m, would be of geothermal interest. Quantitatively they were defined from 400 m to 1250 m.

The aforementioned is also supported in a structural procedure based on the gravimetric information that determines that the (basamento) baseline? is located within a minimum gravimetric reading interpreted as a depression that can be reached on the order of 1200 to 1300 m.

Well CB-2

a) Determine the presence of a geothermal deposit in the Amado Nervo area.

b) Locate the andesite base of the SMO.

c) Prove the geologic model for this area.

d) Recognize the physical characteristics of magnetic susceptibility, density and conductivity of the core material extracted during drilling as well as all relevant data.

e) Establish the distribution of the hydrothermal mineralogy both in its paragenesis as well as its relationship to recent dome vulcanism in this area.

f) Recognize the characteristics that determine two areas of interest with low values of resistivity (5-10 Ohm.m) within the 900 to 1200 m interval and below a depth of 1500 m.

g) Penetrate an area of minimal gravimetry related to a graben structure that parallels the principal regional system (NW-SE).

Well CB-3

a) Determine the presence of a geothermal deposit in the San Pedro-Los Ocotes Domes area.

b) Locate the andesite base of the SMO.

c) Prove the geologic model for this area.

d) Recognize the physical characteristics of magnetic susceptibility, density and conductivity of the core material extracted during drilling as well as all relevant data.

e) Establish the distribution of the hydrothermal mineralogy both in its paragenesis as well as its relationship to recent domes of 100 000 years in Los Ocotes and Los Lobos.

f) Cross the anomaly zone of geothermal interest with values of low resistivity of 5 to 30 Ohm.m.

5.3.- DRILLING RESULTS

Drilling began at the well site CB-1 on the 6th of October 1993 and was completed on the 23rd of March 1994. A maximum depth of 2801 m was reached with a maximum temperature of 115 C.

Drilling at well site CB-2 began on April 10, 1994 and was completed on July 22, 1994. This well has a depth of 1700 m.

Drilling a well site CB-3 began on August 18, 1994 and was completed December 5, 1994 with a maximum depth of 1911 m.

Termination of Drill Sites

The mechanical state of the exploratory drill sites remains as follows:

Site CB-1.- A tube coating (TR) from 9 5/8", from 0 to 1494.28 mbnt. was installed. From there an uncovered (case, drain?) from 8 1/2" to 2801 m. The drill site presents an obstruction near collapse from 2160 m to total depth (Figure 5.1). During drilling 7 cores were extracted at different depths.

Site CB-2.- Remains with TR from 13 3/8" from 0 to 303 mbnt., case uncovered from 12 1/4" to 1506 mbnt.; y case uncovered from 8 1/2" to 1700 mbnt. (Figure 5.2).

Site CB-3.-It has TR from 9 5/8" from 0 to 496 mbnt.; and has an uncovered casement from 8 1/2" to 1911 m (Figure 5.3).

3.-GEOPHYSICAL STUDIES

3.1.-Gravimetry and Magnetometry

Priority #2

Pgs. 9, 10, 11, 12

Upon [illegible] nd magnetic information of the El Ceboruco, N[illegible] both show NW-SE and NE-SW lineaments as [illegible] fined through geologic studies. In order to dete[illegible] ic structure, using these techniques, a section that i[illegible] CB-2 were outlined, Figure 3.3.

By w[illegible] nterpreted: it involves an extensional basin where [illegible] in the southeast section of the Sierra Zapotan, is [illegible].

It wi[illegible] ast part of the Sierra Madre Occidental correspond [illegible] boruco and Tepetiltic associating this with a weak [illegible] ed.

To the west in the Tequilita zone lies a fault system displacing granitic rocks to the aforementioned depth. Following the displacement of the (basamento), integrated into the model, you have the more recent intrusions that led to acidic vulcanism, represented on the surface on the following hills El Fraile, Las Bartolinas, Lobos and Los Domos de san Pedro and Ocotes (Figure 3.1).

3.2.-Geoelectrics

There have been two geoelectric surveys, the first using Electrical Vertical Sounding (SEV) with Schlumberger tetraelectrodico arrangement and the second using Magnetoteluric Sounding (SMT). In both circumstances it was possible to define an anomaly of low resistivity, <30 Ohm.m.

3.2.1-Electrical Vertical Sounding

The minimum resistivity defined by the (SEV), covers the research areas where there is hydrothermal evidence, bordered on the east by the Ceboruco volcano and the town of Ahualamo; and on the west by the Amado Nervo urban area and Los Domos de San Pedro and Los Ocotes, to the southeast bordered by the river Tetiteco, the is structurally related to a NE-SW alignment.

In the section of Figure 3.5 with an E-W direccion, the minimum resistivity can be observed (<30 Ohm.m), it is evident superficially between the Amado Nervo town (west) and

Marquesado (east), relating this with the zones of geothermal alteration, detected in the well GC-6 and CB-2 the the region of Amado Nervo; however, the temperatures were found to be low (105 C). Based on the petrographic study, low resistivity is associated with ancient tectonic alteration.

In another area of the zone the CB-3 well, SEV's 16,17,55, and 33 Figure 3.6, the low resistivity anomaly previously mentioned is evident, defying its superficial behavior due to evidence of continuous minimum values of resistivity at greater depths, associating with a hydrothermal alteration zone of high temperatures as confirmed at the CB-3 well from 600 meters with temperatures greater that 100 C, reaching a depth of 1420 m and 184 C and at 1906 m a stabilized temperature of 189.06 C.

3.2.2.-Magnetoteluric Sounding

As was mentioned previously, this technique can also be used to define a low resistivity anomaly whose limits correspond to the anomaly defined by the SEV. This anomaly is evident at high frequencies indicating that its effect is superficial, however, at low frequency or at a greater depth, three anomaly zones are differenciated, Figure 3.7, relating them to zones of hydrothermal alteration, caused by recent intrusiones, which are: Amado Nervo, San Pedro - Los Ocotes (at the site of well CB-3) and Ahualamo - Tequepexpan.

3.3 Seismology

The study that was recently initiated was for the purpose of evaluating seismic activity in the zone and relate this to the volcanism and tectonism defined in the geological and geophysical studies.

The objective of this new chapter of exploration is to identify active faults and the type of energy associated with them. This is the case in the weak zone formed by the Coapan fault and the Ceboruco Volcano. With respect to vulcanology it is anticipated to be able to identify the model of cause or evolution.

The seismic registers were begun on August 23 of the present with the instalation of five digital seismic stations of three components. The information already compiled indicates a low level of regional activity in the following sites: Ceboruco, Uzeta, La Campana, Tequepexpan, and Tepetiltic.

The location of the stations is integrated into the Ceboruco Seismologic network presented in figure 3.8.

3.4.-Thermometry

Based on the definition of the zones of minimum resistivity and the geologic structure, five sites were located to calculate the thermal gradient to 200 meters. With these wells it was not possible to cross the hot water (45-50 C) aquifer, there were convective phenomena that made the determinations less confident. Based on this drilling two other wells to a depth of 500m was recommended. The location of the seven sites can be seen in Figure 3.9.

Based on the analysis of the recorded temperatures of the deepest wells, and by way of the Lagrange interpolation, values of thermal gradient on the order of 0.150 C/m were obtained the implicate heat fluxes approximately three times greater than the estimated for the Neovolcanic axis (100 mw/m2), related to an unloading of favorable temperature for the location of a hydrothermal system of high temperatures.

3.5.-Correlation of the Geophysical Parameters Using the Geologic Model

While integrating the geophysical data with the geological data it is possible to make the following conclusions with respect to the geologic model of the region, Figure 2.5.

The study area is immersed locally within a depression delimited morphologically to the northeast by the Sierra Madre Occidental and to the southwest by the Sierras de Zapotan y Guamuchil; located within is the volcano Ceboruco and the Dome San Pedro, under which it has been interpreted the possible existence of hot spring that could give way to a geothermal deposit, the heat flow being restricted, most likely in the Ceboruco by way of its principal channel, given the results of the exploratory well CB-1 drilled on its southwest flank. (I have never seen such long sentences in my life).

For the drill site CB-3 the existence of a granitic intrusion (983 m), that could be associated with the volcanic ducts of the San Pedro Dome, Ocotes and/or Lobos, it looks to be associated to the geothermal system therein identified.

RESUMEN

El proyecto geotérmico El Ceboruco, se localiza en la porción sur del estado de Nayarit, en los municipios de Ahuacatlán, San Pedro Lagunillas y Compostela.

La exploración se ha desarrollado en la región del Graben de Tepic-Chapala, en el sector Compostela-Ixtlán del Río en el estado de Nayarit, incluidas las zonas de actividad hidrotermal como Tequepexpan, Valle Verde-Tetitlán, el Volcán El Ceboruco y Los Domos de San Pedro; siendo estas dos últimas las que reúnen las características más sobresalientes desde el punto de vista volcanológico, las que podrían favorecer la existencia de un sistema geotérmico en la región, se han venido realizando trabajos a partir de 1980 con una serie de estudios exploratorios con características regionales y diversos estudios de detalle en las zonas de mayor interés geotérmico.

En particular en los sectores de El Volcán El Ceboruco y Los Domos de San Pedro, se han llevado a cabo estudios de geología de detalle (con análisis petrográficos, geoquímicos de roca y dataciones radiométricas), de geoquímica (análisis isotópicos en las manifestaciones hidrotermales, mediciones de mercurio en los suelos y análisis de la emanometría de radón), estudios de geofísica (Aeromagnetometría, Resistividad, Gravimetría y Magnetotelúria), estudios termométricos, perforación de pozos de gradiente de 200 y 500 m y finalmente la perforación de tres pozos exploratorios profundos entre 1700 y 2800 m, con los consecuentes análisis petrográficos, mineralógicos y de temperaturas de formación en inclusiones fluidas tanto de los ripios como de los núcleos recolectados en las obras de perforación.

Se han realizado 66 muestreos y análisis geoquímicos a las manifestaciones termales con temperaturas superficiales de 17 a 48°C; así como en las fumarolas y suelos vaporizantes del Ceboruco con temperaturas de 84 a 92°C. Solamente los manantiales termales de Uzeta y el pozo de gradiente GC-1 reportan características de salmueras geotérmicas muy diluidas por aguas subterráneas mas someras de reciente infiltración.

La evaluación del potencial geotérmico del proyecto Ceboruco, concluye que el pozo CB-3 es el que hasta ahora presenta una anomalía térmica de interés, y los trabajos de evaluación y prubas de desarrollo del mismo permitiran conocer las paosibilifades de desarrollo y/o la necesidad de efectuar estudios complementarios.

1.- GENERALIDADES

El Programa de exploración realizado a la fecha en la región de el Volcán El Ceboruco y Los Domos de San Pedro en el estado de Nayarit, se ha llevado a cabo a partir de de la década de los '80 con una serie de estudios de caracter tanto regional como local en las zonas de mayor interés geotérmico, tales como los sectores de El Volcán El Ceboruco y Los Domos de San Pedro.

Sectores en los cuales posteriormente se desarrollo la perforación de pozos de gradiente entre los 200 y 700 m y finalmente la perforación de tres pozos exploratorios profundos entre 1700 y 2800 m, con los consecuentes análisis geoquímicos, petrográficos, mineralógicos y de temperaturas de formación, inclusiones fluidas tanto de los ripios como de los núcleos recolectados; en éstos últimos también se han efectuado las determinaciones de densidad y susceptibilidad magnética con el fin de integrar dichos datos a las interpretaciones geofísicas.

1.1.- Localización y Vías de Comunicación

El Proyecto Geotérmico El Ceboruco, queda ubicado en la porción sur del Estado de Nayarit y en el límite noroeste del Estado de Jalisco. Respecto a la capital de Nayarit, Cd. de Tepic, el proyecto se ubica a 80 km al sureste quedando incluidas, entre otras, las poblaciones de Ixtlán del Río, Jala, Ahuacatlán, San Pedro Lagunillas y Compostela (Figura 1.1).

Tomando como base los límites geográficos del estudio geológico regional, el aérea queda comprendida entre los paralelos 20° 40' y 21° 30' de latitud norte y los meridianos 104° 00' a los 105° 00' de longitud oeste, cubriendo una extensión de 9000 km^2 (110 x 80 km).

La principal vía de comunicación es la carretera Federal No. 15 México-Nogales; en el tramo Guadalajara-Tepic. Además de la carretera federal a Puerto Vallarta, en el trayecto Chapalilla-San Pedro Lagunillas. Así como la vía férrea del Ferrocarril del Pacífico que cruza el área uniendo las poblaciones de Ahuacatlán y Compostela.

1.2. Trabajos Previos

- DIAZ OLVERA ARMANDO, 1985.- Evaluación Geotérmica preliminar del Edo. Nayarit. Informe 24/83. CFE, Publicación Interna.
- CEDILLO R. F. Y LIRA H. H., 1985. Reconocimiento y evaluación Geológica de los Recursos Geotérmicos del Estado de Nayarit. Informe 49/85. CFE, Publicación Interna.
- DE LA CRUZ. M. V. Y CASTILLO H. D., 1987. Estudio geológico Estructural de la Zona Termal de Las Cuevas, Nay. Informe 22/87. CFE, Publicación Interna.
- DEPARTAMENTO DE EXPLORACION, 1989. Propuesta para la Perforación Exploratoria en la Zona Geotérmica del Volcán Ceboruco, Nayarit. Informe 13/89. CFE, Publicación Interna.
- DIAZ O. A. Y DE LA CRUZ. M. V.,1985. Estudio Geológico a Semi Detalle de la Zona Geotérmica del Volcán Ceboruco, Nay. Informe 15/85. CFE, Publicación Interna.
- GUTIERREZ N. L. C. A., 1985. Análisis de la Emanometría de Radón en la Zona Geotérmica del Volcán El Ceboruco, Nay. Reporte GG 18/85. CFE, Publicación Interna.
- GEOEVALUACIONES, S.A. DE C.V., 1991. Estudio Magnetotelúrico Ceboruco-Domo de San Pedro, Nay. Contrato CFE-GPG-CLS-08-91.
- GARCIA E. G. H., 1985. Estudio Termométrico de la Zona Geotérmica del Volcán El Ceboruco, Nay. Informe 44/85 CFE, Publicación Interna.
- GARCIA E. G. H., 1991. Estudio Aeromagnético Regional del SE de Nayarit (El Ceboruco-San Pedro-Tepeltitic). Procesamiento Digital y Descripción Caulitativa. Informe 15/91. CFE, Publicación Interna.
- INVESTIGACIONES GEOFISICAS DE MEXICO, S.A. DE C.V., 1991. Estudio Hidrogeológico Regional en el Graben de Tepic, Estado de Nayarit. Contrato CFE-GPG-CLS-02-91.
- PALMA G. S. H., 1985. Estudio de Resistividad de la Zona Geotérmica del Volcán Ceboruco, Nay. Informe 42/85. CFE, Publicación Interna.

- PALMA G. S. H., 1991. Integración de Los Estudios Geoeléctricos de Resistividad en El Ceboruco, Nay. Informe Técnico 01/91. CFE, Residencia El Ceboruco, Nay. Publicación Interna.

- PASTRANA M. E., 1991. Caracterización y Evaluación Ambiental de la Zona Geotérmica El Ceboruco, Nay. Informe Técnico 02/91. CFE, Residencia El Ceboruco. Publicación Interna.

- ROCHA L. V., 1991. Evaluación Geológica-Estructural de la zona termal de Las Cuevas, Domo San Pedro, volcán Cerro Grande, Nay. Residencia El Ceboruco, Nay. CFE, Publicación Interna.

- ROMERO R. F.; SAUCEDO G. R. Y CORTES C. A. 1991. Estudio Geológico Regional del Graben de Tepic-Ixtlán, Nay. Informe 04/91. CFE, Publicación Interna.

- TELLO H. E., 1985. Reconocimiento y Evaluación Geoquímica de Zonas Termales del Estado de Nayarit. Informe 53/85. CFE, Publicación Interna.

2.- GEOLOGIA

Los estudios geológicos llevados a cabo en el proyecto geotérmico El Ceboruco, Nay., son de carácter regional y local, con sus respectivas etapas de campo y gabinete.

2.1.- Geología Regional

Los estudios realizados llegan a cubrir una área de 9,000 kms^2; en donde se ha podido definir la columna litoestratigráfica con dataciones y cartografía, su relación con la actividad tectónica y de la evolución magmática en un marco geológico regional (Figura 2.1).

El proyecto Ceboruco, se localiza regionalmente en los límites de tres provincias fisiográficas a saber:

1) PROVINCIA DE LA SIERRA MADRE DEL SUR. En un fragmento mejor conocido como Bloque Jalisco ó Terreno Guerrero (Tahue). Integrado por rocas sedimentarias marinas del Cretácico parcialmente afectadas por el emplazamiento del gran Batolíto Cordillerano; andesitas, riolitas, ignimbritas de arco de caracter calco-alcalino del Cretácico Superior al Terciario Inferior, sumamente afectadas

por fracturamiento, fallamiento y alteradas por soluciones hidrotermales.

Pertenecientes al Complejo Inferior Volcánico a nivel cordillera relacionado con una margen continental convergente en el que la Placa Farallón era subduccionada por la corteza continental de México, fenómeno conocido como orogenia Laramide.

2) PROVINCIA DE LA SIERRA MADRE OCCIDENTAL. Constituida principalmente por grandes volúmenes de riolitas, ignimbritas, tobas y andesitas de caracter calco-alcalino. Coronados por basaltos alcalinos, que en conjunto forman el Complejo Superior Volcánico del Oligoceno-Mioceno.

Su génesis atribuida a un volcanismo de zona de "rift" atrás de un arco volcánico andesítico por reacción de la corteza terrestre a movimientos de subducción de la Placa Farallón por debajo de la de Norteamérica, en una fase compresiva que se desarrollo a lo largo de la Costa del Pacífico, en adición con pequeñas intrusiones o "recalentamientos". Esta provincia constituye morfológicamente un gran sistema montañoso de orientación NW-SE en mesetas pseudo horizontales y basculadas.

3) PROVINCIA DEL EJE NEOVOLCANICO. Constituye un gran complejo magmático heterogéneo de arco continental del Plioceno al Reciente. De origen subductivo de la Placa de Cocos por debajo de la de Norteamérica, en una franja de orientación E-W. Formada de una gran variedad litológica en riolitas, pómez, andesitas, dacitas, andesitas-basálticas y basaltos tanto calco-alcalinos como alcalinos.

Actividad que demuestra una gran diferenciación magmática a profundidad, y que en superficie da lugar a estrato-volcanes; como el Ceboruco, Tepeltitic, Sanganguey, Navajas etc. y estructuras tipo Volcan en Escudo Cerro Grande,. Calderas del Ceboruco, Tepeltitic y Santa María; y el gran complejo dómico de San Pedro, Los Ocotes, Sta Isabel, Izote, Pochotero junto con un gran número de conos cineríticos alineados NW-SE.

2.2.- Geología Local

En el área de estudio afloran unidades sedimentarias, ígneas intrusivas como extrusivas en un rango cronológico del Mesozoico al Reciente.

La unidad mas antigua es del Cretácico, consiste de calizas en la base y areniscas en la cima, (sector SW) parcialmente se encuentra afectada por procesos de emplazamiento de Batolítos Circumpacíficos de composición granítica y granodiorítica (basamento); así como una secuencia andesítica, riolítica e ignimbrítica del Cretácico Superior al Terciario Inferior, con fallamiento, fracturamiento en fases compresivas (plegamientos), distensivas (fallas normales), transtensionales (fallas laterales), y de alteración hidrotermal, provenientes de la subducción de la Placa Farallón (Orogenia Laramide).

La anterior unidad forma parte del Terreno Guerrero (Tahue), y de forma local de el "Bloque Jalisco".

Durante el Terciario Medio (Oligoceno-Mioceno), tiene lugar una colosal actividad volcánica de riolitas fluidales, ignímbritas, tobas y andesitas, coronadas por pequeñas coladas de basaltos alcalinos. Sus espesores llegan a alcanzar los 500 m para la región de Chapalilla, en pseudo estratos horizontales y basculados de forma general al NE, fracturados, fallados e intemperizados en una orientación NW-SE.

Morfológicamente da lugar a la cadena montañosa de la Sierra Madre Occidental, que tuvo su origen como volcanismo típico de una zona de rift por reacción de la corteza a fenómenos de subducción de la Placa Farallón.

En el Mioceno Superior-Plioceno Temprano?, se reportan procesos erosivos de rocas preexistentes que forman conglomerados y arenas poligmíticas, con depositación sedimentaria de limos y arcillas sin litificar (vulcanosedimentario).

Del Plioceno al Reciente, en la mayor parte del área se aloja una gran cantidad de geoformas volcánicas de interés geotérmico: volcán en escudo Cerro Grande, estratovolcán Ceboruco y Tepeltitic con sus desarrollos precaldéricos, caldéricos y de intracaldera; conos cineríticos Tezontle, Agujerado y Molcajete; domos de Pochotero, Santa Isabel, Las Higueras, El Fraile, Bartolinas, San Pedro, Los Lobos, Los Ocotes, Loma Atravesada, Izote y Las Cuevas que se relacionan con las manifestaciones termales de la zona consistentes en manantiales de agua caliente hasta 48°C y de fumarolas con 92°C. Los productos exógenos presentan una diferenciación magmática calco-alcalina de mayor volumen y alcalina en basaltos de olivino, mugearitas, andesitas, andesitas precaldéras, tobas , riolitas vítreas y dacitas de hornblenda, andesitas-basálticas y flujos de pómez asociados a emplazamientos dómicos .

2.3.- Geología Estructural

El estado actual de los alineamientos preferenciales NW-SE, N-S y NE-SW, a nivel regional forman en conjunto los elementos estructurales distintivos, producto de la interacción subductiva de placas tectónicas en fases compresivas (plegamientos), distensivas (fallas normales), transpresionales (fallas laterales) y procesos de rift.

El proyecto Ceboruco, junto con otros centros eruptivos de afinidad principalmente calco-alcalina del Plioceno al Reciente, se localiza en la porción oeste de la Provincia Magmática de la Faja Volcánica Mexicana, de origen subductivo de la Placa de Cocos por debajo de la de Norteamérica, junto con la asísmica y desvaneciente Placa Rivera subyaciendo al Bloque Jalisco en la Trinchera del Pacífico.

Localmente la zona de estudio se ubica en la parte noroccidental del graben Tepic-Zacoalco con orientación NW-SE. De estructura interna compleja en bloques levantados, hundidos, trasladados y basculados; en un patrón estructural de fallas y fracturas paralelas al graben, cortados por estructuras NE-SW que absorben definidos rangos de extensión. Sistema estructural actualmente en proceso de "rifting", en donde se han emplazado aparatos cineríticos de afinidad alcalina en coexistencia con magmas Pliocenicos-Recientes calco-alcalinos del Volcán Ceboruco y de la Faja Volcánica Mexicana que en gran volumen y relacionados a la subducción rellenaron las depresiones preexistentes.

Los bloques mas elevados se encuentran en los extremos Sur (Bloque Jalisco) de la Sierra Guamuchil; y al Norte con la Sierra de Jala, correspondiente a la provincia de la Sierra Madre Occidental (Figura 2.1). La presencia de estructuras N-S, que afectan principalmente a la SMO se consideran relacionadas a la Tectónica de Basin and Ranges.

2.4. Volcanología

El vulcanismo en la zona del Proyecto Ceboruco, es bastante extenso y continua desde el Terciario hasta tiempos históricos.

Los registros mas remotos son principalmente de arco, andesitas, riolitas, e ignimbritas calco-alcalinas del Cretácico

Superior al Paleoceno-Eoceno, sujetas a procesos compresivos y distensivos que producen una permeabilidad secundaria capáz de alojar un yacimiento geotérmico, asociados con alteración hidrotermal de la Orogenia Laramide. Actividad magmática correspondiente al Complejo Volcánico Inferior de la Sierra Madre Occidental.

Del Oligoceno al Mioceno, tienen lugar grandes emisiones riolíticas, ignimbritas, tobas y andesitas de carácter calco-alcalino subductivas, coronadas por basaltos alcalinos de rift del Mioceno Superior, que pueden constituir una capa sello en un sistema hidrotermal. Secuencia extrusiva que corresponde al Complejo Volcánico Superior de la Sierra Madre Occidental.

A partir del Plioceno, la tectónica tiene un gran desarrollo en la formación de grabens y procesos de rifting continental, asociados a una evolución y diferenciación magmática de interés volcanológico, en la formación de la Faja Volcánica Mexicana. La Depresión Tequepexpan-Ixtlán (Figura 2.1), comienza a ser rellenada por una secuencia extrusiva calco-alcalina de andesitas, riolitas, tobas, dacitas, basaltos y piroclásticos que culminan en la edificación del estrato volcán Ceboruco, con posteriores cambios morfológicos debidos a la constante evolución magmática que culmina en el desarrollo de dos calderas anidadas, sumados a productos asociados a ellas con los flujos de ceniza El Marquesado con edad de 1500 años, y la erupción histórica a finales del siglo pasado. Así como emplazamiento de conos cineríticos de afinidad alcalina en una disposición NW-SE.

Lo anterior podría sugerir la existencia de un sistema hidrotermal o fuente de calor, asociado a la evolución magmática de origen subductivo o de rift (NW-SE), controlado por un sistema estructural regional.

En la depresión "mas hundida" San Pedro-Tepeltitic (Figura 2.2), la evolución y diferenciación magmática es de forma continua a partir del Plioceno al Reciente. Con la edificación del estrato-volcan Tepeltitic de carácter calco-alcalino en andesitas, dacitas y flujos de lava, coronados por una caldera elíptica de erupción pliniana con flujos y caída de ceniza riolítica que rodean al volcán. Con la prosecución ígnea de domos andesíticos intracaldera y dacíticos extracaldera (Las Guilotas), en asociación con la formación de conos cineríticos con lavas mugearíticas (rift) en una orientación NW-SE.

La mayor actividad volcánica de interés geotérmico es el emplazamiento de cuerpos dómicos dacíticos y riolíticos calco-alcalinos de hornblenda, confinados en la porción SE y S del volcán Tepeltitic, con el nombre de Loma Atravesada, Bartolinas, Izote, El Fraile, Las Cuevas, y el domo Santa Isabel; con edades radiométricas de 1.7 a .750 Ma, que guardan una disposición orientada NW-SE y N-S.

La estructura dómica mas relevante por su forma y dimensión corresponde al San Pedro, constituido por la extrusión de tres domos dacíticos contiguos, con edades de 0.850 a 0.790 Ma, en una disposición elíptica NW-SE (4 x 2.5 km) y una altura máxima de 2000 msnm, que probablemente se desarrolló o emplazó dentro una estructura caldérica. Asociados a estos cuerpos, se tienen depósitos de material piroclástico, flujos de pómez y ceniza interestratificada, en los que se pueden hallar xenolítos de intrusivos, además de los manantiales termales con mayor termalidad reportada de 48°C en Las Cuevas.

La actividad ígnea continua en la "depresión" con la diferenciación y emplazamiento del domo andesítico La Atarjea con 0.530 Ma, y concluye con las mas recienteses extrusiones diferenciadas del domo Los Lobos con 0.180 Ma, y el domo Los Ocotes de 0.101 Ma.

La anterior secuencia ígnea en la "depresión", es considerada como la responsable generadora de la termalidad en la zona.

2.5 Modelo Geológico

A partir del análisis de los estudios geológicos superficiales se ha estructurado el siguiente modelo:

La última fase del desarrollo tectónico en la zona consistió en una extensión pura de dirección NE-SW, provocando la formación de una estructura tipo graben (Graben del Ceboruco) de dirección casi E-W en el área del Ceboruco y NW-SE en el área de Los Domos de San Pedro, afectando a las rocas de las secuencias del Bloque Jalisco y de La Sierra Madre Occidental cuyo límite se infiere en el centro del graben.

Tal tectonismo provocó fallamiento, fracturamiento, deslizamientos y basculamientos de aquellas secuencias litológicas, constituidas en forma general de la base a la cima por granitos y granodioríтas los que conforman el piso basal y sobre el que se encuentran calizas y areniscas afectadas por el cuerpo intrusionante en la zona suroeste del área (Sierra de Zapotán);

andesitas, ignimbrítas y riolítas que conforman la parte superior del Bloque Jalisco del Terciario Inferior (Sierra de Guamuchil), y de la Sierra Madre Occidental del Terciario Medio Superior (Figura 2.4).

Sobreyaciendo a las secuencias mencionadas se encuentra el vulcanismo basáltico, andesítico, dacítico y riolítico del plioceno-pleistocénico reciente, que superficialmente conforma los diferentes aparatos volcánicos, resaltando el Ceboruco y los Domos de San Pedro por su elevación.

Desde el punto de vista geotérmico, la secuencia andesítica base de la Sierra Madre Occidental, es la unidad que se considera, la almacenadora del posible yacimiento hidrotermal, debido a la intensa deformación compresiva, fallada y fracturada que produce una buena permeabilidad, en tanto que las ignímbritas y riolítas constituyen la capa sello de yacimiento, y la fuente de calor asociada al vulcanismo Cuaternario y Reciente en la región.

3.- ESTUDIOS GEOFISICOS

3.1.- Gravimetría y Magnetometría

Al analizar e interpretar la información gravimétrica y magnética del Proyecto Geotérmico El Ceboruco, Nay., Figuras 3.1 y 3.2, ambas presentan lineamientos NW-SE y NE-SW, asociados con el patrón estructural regional definido mediante los reconocimientos geológicos. Para determinar el comportamiento geológico estructural en el subsuelo, mediante éstas técnicas, se trazó una sección que incluyera las localidades de los pozos CB-1 y CB-2, Figura 3.3.

Mediante dicha sección se interpretó el siguiente modelo: se trata de una cuenca extensional en donde el basamento que aflora en el sector suroeste, Sierra de Zapotán, se encuentra afallado en la parte central a una profundidad de entree 5 y 7 km.

Se considerá que los límites de la Sierra Madre Occidental al noreste, corresponden al lineamiento NW-SE de los volcanes Ceboruco y Tepetiltic asociándose éste a una zona de debilidad cortical por la cual se emplazaron dichos centros eruptivos.

Al occidente en la zona de Tequilita existe un sistema de fallas que desplazan a las rocas graníticas a la profundidad mencionada. Posterior al desplazamiento del basamento, se ha integrado en el model, se tiene el emplazamiento de intrusiones más recientes que dieron lugar al vulcanismo ácido, representado en superficie por los cerros El Fraile, Las Bartolinas, Lobos y Los Domos de San Pedro y Ocotes (Figura 3.1).

3.2.- Geoeléctricos

Se efectuaron dos levantamientos geoeléctricos, el primero con la modalidad de Sondeos Eléctricos Verticales (SEV) con arreglo tetraelectródico Schlumberger y el segundo mediante Sondeos Magnetotelúricos (SMT). En ambos se logró definir una zona anómala de mínima resistividad, <30 Ohm.m.

3.2.1.- Sondeos Eléctricos Verticales

El mínimo resistivo definido por los (SEV), cubre las áreas de manifestaciones hidrotermales presentes en el sector de estudio, delimitándose al oriente por el Volcán Ceboruco y la población del Ahualamo; en tanto que al occidente se define en las inmediaciones del poblado de Amado Nervo y Los Domos de San Pedro y Los Ocotes, al sureste se encuentra limitado por el curso del Río Tetiteco; el que se relaciona estructuralmente a un lineamiento NE-SW, Figura 3.4.

En la sección de la Figura 3.5 con una dirección E-W, se observa el mínimo resistivo (<30 Ohm.m), el que se muestra superficialmente entre los poblados de Amado Nervo (al poniente) y Marquesado (al oriente), relacionándose éste, con las zonas de alteración hidrotermal detectadas en los pozos GC-6 y CB-2, en la región de Amado Nervo; sin embargo las temperaturas encontradas fueron bajas (105°C). Considerándose por el estudio petrográfico, que los valores bajos de resistividad tienen asociación con la alteración provocada por un vulcanismo antiguo.

Por otro lado en la zona del pozo CB-3, SEV's 16, 17, 55 y 33, Figura 3.6, se presenta nuevamente la anomalía de baja resistividad mencionada, que difiere en su comportamiento superficial, al evidenciar continuidad de los valores mínimos de resistividad a mayores profundidades, asociándose, a una zona de alteración hidrotermal de alta temperatura como lo ha confirmado el pozo CB-3 desde los 600 metros con temperaturas mayores a los

100°C, alcanzando a la profundidad de 1420 m los 184°C, y a los 1906 m una temperatura estabilizadas de 189.06°C.

3.2.2.- Sondeos Magnetotelúricos

Como se mencionó anteriormente, también con esta técnica, se define una anomalía de baja resistividad cuyos límites son los correspondientes a la anomalía definida por los SEV. Esta anomalía se presenta a frecuencias altas indicando que su efecto es superficial, sin embargo a bajas frecuencias ó a mayor profundidad se diferencian tres zonas anómalas, Figura 3.7, relacionándolas a zonas de alteración hidrotermal, provocadas por intrusiones recientes, dichas zonas son: Amado Nervo, San Pedro - Los Ocotes (sector del pozo CB-3) y Ahualamo - Tequepexpan.

3.3.- Sismología

El estudio recientemente iniciado se programó para evaluar la actividad sísmica de la zona y su relación con el vulcanismo y la tectónica que se define en los estudios geológicos y geofísicos.

En esta nueva etapa de exploración se pretende identificar las fallas que sean activas y el tipo de esfuerzos que se ejercen. Tal es el caso de la zona de debilidad formada por la falla Coapan y el Volcán Ceboruco. En el aspecto vulcanológico se espera identificar el modelo que da lugar al vulcanismo actual o en evolución.

Los registros sísmicos se iniciaron el 23 de agosto del año en curso con la instalación de cinco equipos sismológicos de tipo digital de tres componentes, la información hasta ahora recopilada indica un bajo nivel de actividad regional en los sitios Ceboruco, Uzeta, La Campana, Tequepexpan y Tepetiltic.

La ubicación de las estaciones que integran la Red Sismológica del Ceboruco se presentan en la Figura 3.8.

3.4.- Termometría

En base a la definición de las zonas de mínimos resistivos y al comportamiento geológico estructural, se ubicaron cinco sitios para calcular el gradiente térmico a 200 metros. Con estos pozos no se logró atravesar el acuífero de agua caliente (45-50°C) por lo cual se presentaron fenómenos convectivos, que hicieron poco confiables las determinaciones. Por tal motivo se recomendaron dos pozos adicionales a 500 m de profundidad. La ubicación de los siete sitios se observa en la Figura 3.9.

Mediante el análisis de los registros de temperatura de los pozos mas profundos, a través de la interpolación de Lagrange, se obtuvieron valores de gradiente térmico del orden 0.150 °C/m, que implican flujos de calor aproximadamente tres veces mayores al estimado para el Eje Neovolcánico (100 mw/m^2), relacionándose con una descarga de calor favorable para la yacencia de un sistema hidrotermal de alta temperatura.

3.5.- Correlación de los Parámetros Geofísicos con el Modelo Geológico

Al integrar la información geofísica con los datos geológicos es posible plantear las siguientes conclusiones respecto al modelo geológico de la región, Figura 2.5.

La zona de estudio se encuentra inmersa, localmente, dentro de una depresión delimitada morfológicamente al noreste por la Sierra Madre Occidental y al suroeste por las Sierras de Zapotán y Guamuchil, quedando emplazados dentro de ésta, el volcán Ceboruco y Domo de San Pedro, bajo los cuáles se ha interpretado que es posible la existencia de fuentes de calor que puedan dar lugar a un Yacimiento Geotérmico; quedando restringida la conducción de calor, probablemente en el Ceboruco a través del conducto principal de éste, dados los resultados del pozo exploratorio CB-1 perforado en su flanco suroeste.

Para el sector del pozo CB-3 la existencia de un intrusivo granítico (983 m), que pudiese asociarse con los conductos volcánicos del Domo San Pedro, Ocotes y/o Lobos, parece ser el asociado al sistema geotérmico ahí identificado.

4.- GEOQUIMICA

La aplicación de técnicas geoquímicas ha llegado a ser parte integral de cualquier investigación relacionada con la exploración y explotación de recursos geotérmicos. Debido a que actualmente se está perforando el tercer pozo profundo (CB-3). exploratorio, se llevo a cabo la revisión de la información geoquímica existente hasta la fecha.

4.1.- Muestreo de Agua y Gases

El presente trabajo se desarrolló con el objeto de conocer las características geoquímicas del acuífero somero y su interacción con fluidos geotérmicos. Para esto se utilizó la composición química del agua de 57 manantiales y 9 pozos termales localizados en los alrededores del volcán Ceboruco.

En la cima del volcán del Ceboruco existen fumarolas y suelos vaporizantes con temperaturas de 84°C a 92°C. Los suelos vaporizantes se encuentran en la pared interior de la primera caldera con una temperatura superficial de 84°C. Cabe mencionar que no se pueden muestrear por la baja presión que presentan. Sin embargo en estas manifestaciones no se aprecia olor a ácido sulfhídrico.

La otra localidad es el llamado cráter Cinco Bocas de la segunda caldera, en donde se encuentran las fumarolas más representativas con una temperatura superficial de 92°C, notándose depositación de azufre elemental y percibiéndose olor a H_2S. El análisis químico de los gases reveló la existencia de cantidades considerables de elementos como el CO_2, H_2 y H_2S que son gases representatitivos de un sistema geotérmico de alta temperatura.

4.2.- Parámetros Geoquímicos

Con el objeto de clasificar geoquímicamente el agua de las manifestaciones se graficó el contenido relativo de HCO_3, Cl y SO_4 de las manifestaciones analizadas. A excepción de las muestras de Uzeta, y el pozo Santa Isabel (GC-1), cuyos caracteres geoquímicos son clorurado-sódico, el resto presenta un caracter bicarbonatado-sódico (Figura 4.1). En la tabla 4.1 está referida la composición química de las muestras analizadas.

Las muestras de agua de Uzeta (M24) y pozo Santa Isabel (M66), son las únicas que presentan evidencias de estar interaccionando con fluidos de origen profundo. Esto debido a que la concentración de boro y litio están presentes en cantidades significativas (1.2 y 3.5 ppm, respectivamente).

También es importante mencionar que en el caso del pozo Santa Isabel al graficar el contenido relativo de Na:K:Mg (Figura 4.2)., se desplaza hacia la zona de equilibrio parcial aunque a temperaturas bajas. El resto de las captaciones se ubican en la zona de aguas someras.

Se aplicó el método desarrollado por Giggenbach, 1988; el cual permite determinar tanto el contenido de CO_2 como la temperatura del "último equilibrio" del agua con la roca antes de aflorar a la superficie (Figura 4.3). En esta figura se observa que solamente el agua del pozo de gradiente Santa Isabel tiende al equilibrio con la roca y se ubica en la zona de formación de calcita.

El resto de las captaciones se mueven hacia la zona de formación de calcita. Lo que indica que los fluidos ascienden muy rápido a la superficie y no llegan a equilibrarse con la roca con la que están en contacto. Las temperaturas del último equilibrio varían de 50°C a 70°C. La diferencia entre las temperaturas se debe a la velocidad del ascenso desde la profundidad y a la cinética de la interacción agua-roca. Esto indica que se trata de aguas someras que se han equilibrado con la roca a bajas temperaturas.

En la Figura 4.4 están representados en planta los valores de cloruros registrados por todas las captaciones analizadas en la zona. Se puede ver en la gráfica que los manantiales de Las Guámaras (M26), Agua Caliente de las Las Cuevas (M40), Agua Mineral (M55), Las Guásimas (M59), Pozo Santa Isabel (M66) y Uzeta (M24) son los que presentan los valores mas altos de cloruros (105 a 225 ppm). Además también registraron las más altas temperaturas superficiales (25 a 48°C). Así como las más altas concentraciones del elemento boro con 1.2 (M24) a 4 ppm (M40), que sugieren circulación profunda.

Es importante mencionar que el alineamiento NW-SE de los valores anómalos (Cloruros) en la zona coinciden con los rasgos geológicos principales formados por la fractura del Río Tetitlán y los domos de orientación NW-SE del que forma parte el Domo San Pedro.

Por lo antrior, debido a que estos manantiales de mayor termalidad se encuentran en la margen izquierda de Río Tetitlán permiten suponer que la fuente de calor que las influencia podría ser el Domo San Pedro. Aunado a esto las características geoquímicas que presenta el pozo artesiano de gradiente Santa Isabel con temperatura de 42°C, y valores altos de cloruros y boro con respecto a las aguas locales permite también suponer que ha profundidad podrían encontrarse condiciones geotérmicas más interesantes.

4.3.- Geotermometría de Fase Líquida

Una de las suposiciones fundamentales en la aplicación de los geotermómetros es que el equilibrio agua-roca se efectúa a profundidad y a elevadas temperaturas. En el caso de los manantiales de El Ceboruco, el geotermómetro de K/Mg, sugiere temperaturas inferiores a 100°C lo cual indica que son manantiales de circulación somera que se han equilibrado con la roca a bajas temperaturas. Debido a lo anterior no es recomendable aplicar el resto de las geotermómetros, ya que no se cumple con la suposición fundamental.

4.4.- Impacto Ambiental

Debido a que en la zona se iniciaron las perforaciones profundas, es importante establecer las características químicas de los diferentes cuerpos de agua en condiciones naturales (no perturbadas por la explotación geotérmica) para conocer la calidad del agua que existe en la zona y su posible uso.

Para la clasificación de la calidad del agua para uso agrícola, se empleo la Figura 4.5; la cual está basada en la conductividad eléctrica y la relación de absorción de sodio. Se puede ver en ella, que la gran mayoría de las captaciones del Ceboruco se ubican en la región de aguas de buena calidad para uso agrícola. Sin embargo, las muestras 31, 59, 20, 40 presentan una salinidad media pero tienen un alto peligro por sodio intercambiable. Las muestras 55 y 24 presentan alta salinidad con muy alto peligro de sodio intercambiable.

También de acuerdo con el contenido de boro la gran mayoría de las captaciones se encuentran clasificadas como aguas de buena calidad. Sin embargo las muestras de Las Guámaras (M26), Agua Caliente (M40), P. del Río (M55) y Santa Isabel (M66) presentan concentraciones de boro mayores de 3 ppm lo que indica que su uso debe ser reservado para cultivos moderadamente sensibles al boro.

5.- PERFORACION DE POZOS EXPLORATORIOS

La conjunción de los trabajos técnicos determinaron la localización de 3 pozos profundos de 2000 m (Figura 3.9), determinarán la existencia de una o varias zonas anómalas termales relacionadas con un yacimiento geotérmico susceptible de ser aprovechado en la generación de energía eléctrica.

POZO CB-1.- Se perforó en la ladera sur al volcán Ceboruco, bajo las coordenadas X = 596,800, Y = 2'332,500, y Z = 1130 msnm. En una parcela que pertenece al Ejido del Marquesado, municipio de Ahucatlán.

POZO CB-2.- Se perforó a 18 km al poniente del CB-1, en las coordenadas X = 529,850 Y = 2'333,400 y Z = 850 msnm, en una parcela al ejido Amado Nervo, municipio de San Pedro Lagunillas.

POZO CB-3.- Se perforó a 3.4 km al noreste del Domo Central de San Pedro y a 9 km al nor-noreste del pozo CB-2, bajo las coordenadas X = 530,950, Y = 2'342,650 y Z = 1220 msnm. En una parcela del municipio de San Pedro Lagunillas.

5.1.- Argumentos Técnicos en la Selección de Sitios

Los argumentos técnicos empleados para la selección de los sitios a perforar fueron geoquímicos, geológicos y geofísicos. Para el caso del sitio del pozo CB-1, fue el determinar la presencia de un yacimiento geotérmico asociados al volcán Ceboruco. Con los estudios geoquímicos se muestrearon y analizaron los gases de las fumarolas y suelos calientes con temperaturas máximas de 92°C, de los cráteres del aparato volcánico del Ceboruco (Cinco bocas), arrojando como resultado bióxido de carbono, ácido sulfhídrico e hidrógeno en cantidades comparables a las encontradas en pozos geotérmicos de alta entalpía.

Con la aplicación de la geotermometría de fase gaseosa se calcularon temperaturas de fondo del orden de 267°C; el estudio de mercurio mostró porcentajes mayores a los obtenidos en alguna zona geotérmica del país.

Los estudios geológicos regional y detalle concluyeron que el edificio volcánico debe estar relacionado a profundidad con una cámara magmática apenas en proceso de enfriamiento, ya que su última erupción es histórica (1870 - 1875), y relacionado a una zona con un desarrollo tectónico importante.

Los levantamientos geofísicos con el método de MT, recomendaron el sitio tomando como base la suposición de que el conductivo intermedio por su forma y sus valores de resistividad ahí detectados, estuviesen asociados al yacimiento geotérmico; los estudios gravimétricos y aeromagnéticos arrojaron como resultados que las anomalías de mínimos ahí presentes se relacionan con una zona de interés geotérmico.

Para el sitio del pozo CB-2, los argumentos geoquímicos se tienen en el análisis de las manifestaciones termales de los valles de Tetitlán-Valle Verde y el de Amado Nervo. Constituidos por manantiales con temperaturas máximas de 48°C. Además los elementos detectados sugieren que son indicadores de actividad geotérmica. Las temperaturas estimadas con el geotermómetro de K-Mg van desde los 53 hasta 68°C; sin embargo esta estimación se ve restringida por la naturaleza secundaria de los manantiales.

Los estudios de caracter geológico se basan en el desarrollo vulcanológico de la zona donde se han emplazado una serie de domos de composición dacítica, riolítica y andesítica a partir del Cuaternario Inferior (1.7 Ma). Tales estructuras se encuentran alineadas en una dirección NW-SE, de una zona de debilidad que fue aprovechada para el ascenso y emplazamiento de las formas dómicas.

Los argumentos geofísicos (geoeléctricos y gravimetría), permitieron apoyar el sitio del CB-2 ya que el conductivo intermedio presenta valores de resistividades mínimos en esa zona que pudiesen estar relacionados con alta saturación o alteración hidrotermal, el análisis cualitativo de la anomalía de Bouguer detectó una zona de mínimo gravimétrico que es interpretada como una zona de graben o semigraben con orientación NW-SE.

Para el sitio del pozo CB-3, los estudios geoquímicos practicados a la manifestación de la Guásimas con 31°C, y la mas cercana al sitio, indican que tienen concentraciones de boro, sulfatos y cloruros como indicadores de actividad geotérmica.

Los estudios de caracter geológico apoyan el aérea debido que existe el emplazamiento de un complejo dómico calco-alcalino dacítico y riolítico con edades de 0.850 a 0.790 Ma, para el San Pedro hasta los 0.101 Ma, para el domo Los Ocotes. Orientados en una franja de debilidad NW-SE y N-S, en asociación con coladas mugearíticas, así como el de encontrar la andesita basal de la SMO.

Los estudios de geofísica eléctrica, arrojaron como resultado una correlación muy importante entre las anomalías de bajas resistividades con posibles zonas de fracturamiento o de calor. Además la anomalía de Bouguer regional presenta un mínimo gravimétrico en el área de los domos de San Pedro, que pudiera estar relacionada a una zona de depresión donde se emplazaron las formas dómicas recientes.

5.2.- OBJETIVOS

POZO CB-1.

a) Determinar la presencia de un yacimiento geotérmico asociado al Volcán Ceboruco.

b) Encontrar el yacimiento en la unidad basal andesítica de la Sierra Madre Occidental, Oligoceno-Mioceno, que debido a la intensa deformación compresiva se encuentra plegada, fallada, y fracturada produciendo una buena permeabilidad secundaria, constituyendo un acuífero de 600 - 700 m de espesor favorable para la exploración de un eventual yacimiento.

c) Comprobar el modelo geológico propuesto.

d) Conocer las características físicas de susceptibilidad magnética, densidad, conductividad en los núcleos extraídos durante la perforación. Además de su datación.

e) Establecer la distribución de la mineralogía hidrotermal así como de su paragénesis, y su relación con el vulcanismo del Ceboruco.

f) Determinar que caracteristicas de las rocas controlan las anomalías de baja resistividad obtenidas por el método magnetotelúrico, que por sus valores cualitativos menores de 10 Ohm.m, resultarían tener un interés geotérmico. Cuantitativamente se definieron a partir de los 400 m hasta los 1250 m.

Lo anterior se encuentra también sustentado en un comportamiento estructural del "basamento" en base al análisis de la información gravimétrica, que determina que el basamento se encuentra dentro de un mínimo gravimétrico interpretado como una depresión que sería alcanzado en el orden de los 1200 y 1300 m.

POZO CB-2

a) Determinar la presencia de un yacimiento geotérmico en el área de Amado Nervo.

b) Encontrar la base andesítica de la SMO.

c) Comprobar el modelo geológico para esta zona.

d) Conocer las características físicas de susceptibilidad magnética, densidad y conductividad en los núcleos extraídos durante la perforación. Además de su datación.

e) Establecer la distribución de la mineralogía hidrotermal así como su paragénesis en relación al vulcanismo dómico reciente de la zona.

f) Conocer las caracteristicas que determinan dos zonas de interés con valores de baja resistividad (5-10 Ohm.m) en el intervalo de los 900 a 1200 m, y por debajo de los 1500 m de profundidad.

g) Penetrar a una zona de mínimo gravimétrico relacionada con una estructura tipo graben paralela al sistema regional principal (NW-SE).

POZO CB-3

a) Determinar la presencia del un yacimiento geotérmico en el área de los Domos San Pedro-Los Ocotes.

b) Encontrar la base andesítica de la SMO.

c) Comprobar el modelo geológico para esta zona.

d) Conocer las características físicas de susceptibilidad magnética, densidad y conductividad en los núcleos extraídos de la perforación del pozo. Además de su datación.

e) Establecer la distribución de la mineralogía hidrotermal así como su paragénesis, y su relación con los domos recientes de 100 000 años de Los Ocotes y Los Lobos.

f) Atravezar la zona anómala de interés termal con valores de baja resistividad de 5 a 30 Ohm.m.

5.3.- RESULTADOS DE LA PERFORACION

El pozo CB-1, se inició a perforar el 6 de octubre de 1993 y concluyó el 23 de marzo de 1994. Alcanzó un desarrollo máximo de 2801 m de profundidad, con una temperatura máxima estabilizada de 115°C.

El pozo CB-2, se inició a perforar el 10 de abril de 1994 y concluye el 22 de julio de 1994. Este pozo tiene una profundidad de 1700 m.

El pozo CB-3, se inició a perforar el 18 de agosto de 1994 y concluyó el 5 de diciembre de 1994, con un desarrollo máximo de 1911 m.

5.4.- Terminación de Pozos

El estado mecánico de los pozos exploratorios profundos quedó de la siguiente manera:

POZO CB-1.- Se instaló con tubería de revestimiento (TR) de 9 5/8", de 0 a 1494.28 mbnt. De ahí con agujero descubierto de 8 1/2" hasta los 2801 m. El pozo presenta una obstrucción por derrumbe de 2160 m hasta la profundidad total (Figura 5.1). Durante la perforación se extrajeron 7 núcleos a diferentes profundidades.

POZO CB-2.- Quedo con TR de 13 3/8" de 0 a 303 mbnt, agujero descubierto de 12 1/4" hasta 1506 mbnt.; y agujero descubierto de 8 1/2" hasta 1700 mbnt (Figura 5.2).

POZO CB-3.- Tiene TR de 9 5/8 de 0 a 496 mbnt; y lleva agujero descubierto de 8 1/2" hasta 1911 m (Figura 5.3).

6.- EVALUACION GEOTERMICA

6.1.- Columna Litológica

La litología atravesada por el Pozo CB-1, consiste de piroclásticos pertenecientes al edificio volcánico del Ceboruco con un espesor de 200 m (de 0 a 200 m), lavas andesíticas, riolíticas, basálticas y tobas con un espesor de 214 m (200 a 414 m).

De 414 a 494 m se tiene un conglomerado heterogéneo con un espesor de 80 m, el que seguramente se deposito durante el Plioceno, una secuencia gruesa de lavas andesíticas, basálticas, brechas andesito-basálticas, tobas y basaltos magnéticos con un espesor de 866 m (494 a 2360 m) y pertenecientes tentativamente al Mio-Plioceno, cuyo origen es fisural y relacionada con la apertura de la fosa del Ceboruco. Una unidad riolítica e ignimbrítica probablemente de la secuencia litológica del Bloque Jalisco con un espesor de 400 m (2360 a 2760 m); y finalmente unas lavas andesíticas pertenecientes a la secuencia del Bloque Jalisco? (Figura 5.1).

La litología atravesada por el Pozo CB-2, consiste de un horizonte con 26 m de espesor (0 a 26 m) de flujos de ceniza y bloques dacíticos, resultado de un colapso de un frente de flujo o del emplazamiento de los Domos de San Pedro. Lavas basálticas vesiculares compactas de olivino del volcán en Escudo Cerro Grande con una edad de 1.1 Ma y espesor de 22 m (de 26 a 48 m). Tobas Pumicíticas con un espesor de 92 m (de 48 a 140 m); Dacitas de hornblenda con un espesor de 186 m (de 140 a 326 m), Lavas basálticas con un espesor de 36 m (326 a 362 m). Un depósito lacustre vulcanosedimentario constituido por arcillas, limos, arenas, grabas y tobas pumicíticas con espesor de 178 m (de 362 a 540 m). Una unidad riolítica con espesor de 32 m (de 540 a 572 m). Un paquete de lavas andesíticas con espesor de 260 m (de 572 a 832 m); y finalmente la secuencia del Bloque Jalisco representada por: una unidad de ignimbritas líticas con espesor de 133 m (832 a 965 m), y un potente espesor de lavas andesíticas de 735 m (de 965 a 1700 m), la cual se encuentra intrusionada por una cuarzodiorita a los 1510 m de profundidad (Figura 5.2).

La litología cortada por el Pozo CB-3, consiste de riolitas fluidales con inyecciones de obsidiana con una edad 0.109 Ma y espesor de 266 m (de 0 a 266 m de profundidad). Una unidad de dacitas de hornblenda y mica con un espesor de 234 m (de 266 a 500 m), correlacionable con el emplazamiento de los domos de San Pedro con una edad de 0.790 Ma. Una unidad de dacitas con fuerte alteración hidrotermal con un espesor de 360 m (de 500 a 860 m). Un paquete de lavas andesíticas vítreas con un espesor de 68 m (de 860 a 928 m), y finalmente un cuerpo intrusivo (stock , boss o apófisis de un batolíto) de composición granito calco-alcalino de biotita , piroxeno (enstatita), óxidos, ilmenita y magnetita, compacto de color rosado. Con alteración hidrotermal (argilitización) de plagioclasas, feldespatos y ferromagnesianos en la matriz, con un espesor de 983 m (de 928 a 1911 m), Figura 5.3.

6.2.- Alteración Hidrotermal

En el pozo CB-1, la mineralogía de alteración hidrotermal detectada es de bajo grado, representada por calcita en fallas y remplazamiento de plagioclasas, clorita, prehnita, zeolitas y cuarzo. En forma general estos se presentaron a partir de los 1200 hasta los 2801 m de profundidad.

La presencia de epidota fue detectada en traza de falla. El estudio de inclusiones fluidas en calcita, determinaron temperaturas de formación de 137°C a la profundidad total. Los registros de temperatura efectuados concluyen que el pozo tiene un gradiente normal.

En el pozo CB-2, la mineralogía hidrotermal es de bajo grado representada por clorita, cuarzo, calcita , oxidos, pirita y calcopirita que se presentan a partir de los 600 a los 1700 m. La epidota esta presente a partir de los 900 m.

La aparición de turmalina indica una actividad hidrotermal antigua. Los registros de temperatura durante la perforación concluyen que el pozo tiene un gradiente normal (ligeramente anómalo).

En el pozo CB-3, la mineralogía de alteración hidrotermal queda representada por cuarzo, calcita en fallas y remplazamiento de plagioclasas; la biotita esta alterada en parte a clorita, los piroxenos en arcillas, pirita, y hematita que se presentan a partir de los 500 m, mientras que la epidota (remplazamiento), arcillas y sericita se encuentran de los 900 m hacia el fondo.

De los tres pozos, el que presenta mineralogía de alteración hidrotermal importante o relacionada con temperaturas mayores de 200°C es el CB-3.

Lo cual queda demostrado por la serie de registros de temperatura con elementos Kuster, en complemento con las medidas en los lodos de perforación de "entrada y salida". Por lo que se concluye que la zona esta relacionada con un sistema geotérmico.

6.3.- Temperaturas Medidas

Durante la perforación se llevaron a cabo una serie de registros de temperatura de fondo, utilizando los elementos de equipo Kuster, en diferentes intervalos de profundidad como a diversos intervalos de tiempo, segun se exibe a continuación.

REGISTROS DE TEMPERATURA EN EL POZO CB-1

REGISTROS	HORAS DE REPOSO	TEMPERATURA MAXIMA	INTERVALO DEL REGISTRO
T-5	12	34.00°C	0 a 495 m
T-7	12	50.71°C	0 a 994 m
T-12	20	65.80°C	900 a 1494 m
T-18	25	90.00°C	1000 a 1987 m
T-21	24	96.20°C	1500 a 2481 m
T-25	24	102.70°C	0 a 2583 m
T-27	18	110.10°C	2000 a 2785 m

La temperatura máxima estabilizada por el método Horner fue de 115 °C a los 2801 m (gradiente termal normal).

REGISTROS DE TEMPERATURA EN EL POZO CB-2			
REGISTRO	HORAS DE REPOSO	TEMPERATURA MAXIMA	INTERVALO DEL REGISTRO
T-3	18	52.0°C	0 a 660 m
T-6	18	77.8°C	500 a 1050 m
T-9	18	92.3°C	800 a 1500 m
T-13	24	105.4°C	900 a 1691 m
La temperatura máxima estabilizada por paquete TEMPEST es de 111.87°C (gradiente termal normal ligeramente anómalo).			

REGISTROS DE TEMPERATURA EN EL POZO CB-3			
REGISTROS	HORAS DE REPOSO	TEMPERATURA MAXIMA	INTERVALO DEL REGISTRO
T-4	24	127.5°C	0 a 791 m
T-8	24	156°C	450 a 1186 m
T-11	18	171.5°C	450 a 1420 m
T-15	24	183.3°C	0 a 1906 m
La temperatura máxima estabilizada por el método Horner a los 1906 m es de 198°C. (gradiente termal anómalo).			

6.4.- Zonas de Perdidas de los Fluidos de Perforación

Durante la construcción de los pozos se obtuvieron registros de perdidas de fluidos o lodos de circulación (Registros Continuos, Figuras 5.1 a 5.3). Se puede distinguir que los principales intervalos o zonas con pérdidas totales de 50 m^3/h se tienen en las porciones superficiales de 0 a 300 m, correlacionables con las propiedades físicas primarias de las unidades extrusivas recientes de la Faja Volcánica Mexicana. Además de un horizonte pequeño con perdida total en el intervalo de 600 m (CB-2). Existe también una perdida mínima predominante casi nula a lo largo del pozo (CB-1) del orden de 1.2 a 12 m^3/h, asociables con pequeñas zonas de fracturamiento y fallamiento parcialmente sellado. Es de importancia notar que la densidad ligeramente alta del lodo de perforación influyó en las bajas perdidas de circulación (Figuras 5.1 a 5.3).

6.5.- Objetivos Geológicos-Geofísicos Alcanzados

Estos quedan restringidos a los resultados obtenidos de la perforación de los 3 pozos profundos.

POZO CB-1.- Alcanzó una profundidad total de 2801 m. Los resultados obtenidos son:

a) No existe un yacimiento geotérmico, ni zona anómala termal asociada al volcán Ceboruco.

b) El yacimiento en la unidad basal andesítica de la SMO no se encontró.

c) Se estableció la columna litológica, con la actualización del Modelo Geológico.

d) Se hicieron mediciones de densidad, y algunas de susceptibilidad magnética en los núcleos de diferentes profundidades, quedando pendiente los de conductividad y las dataciones.

e) Se permitió establecer la distribución mineralógica hidrotermal, así como su paragénesis en adición con el gradiente termal.

f) Se determinó que la zona de bajos resistivos menores de 10 Ohm.m, que se cortaron en el intervalo de 400 a 1200 m, no tienen relación con un yacimiento geotérmico o anomalía termal.

g) La interpretación gravimétrica demostró que la zona corresponde a una gran depresión (graben), del basamento granítico.

POZO CB-2.- La profundidad total de este pozo es de 1700 m. Los resultados obtenidos de la perforación concluyen:

a) No existe un yacimiento geotérmico, ni de anomalía termal en la zona de Amado Nervo.

b) Las condiciones de fracturamiento, fallamiento y permeabilidad que pudiera tener la andesita basal de la SMO, para alojar un yacimiento asociadas al complejo dómico del Plioceno-Reciente son nulas.

La zona de permeabilidad reportada en los registros de perdida total de circulación a los 600 m, indica que corresponde tal vez a un contacto litológico o bien a un intemperismo superficial de la cima de un cuerpo andesítico.

c) Se permitió establecer la columna litológica y actualizar el Modelo Geológico.

d) Se realizaron mediciones de densidad para los núcleos extraídos durante la perforación. Quedando pendientes por efectuar los de susceptibilidad magnética, conductividad y datación.

e) Se estableció la distribución mineralógica hidrotermal así como paragénesis, en adición a la medición del gradiente termal.

f) Los valores de baja resistividad 5 a 10 Ohm.m, que fueron cortados en el intervalo de 900 a 1200 m y por debajo de los 1500 m, no tienen relación alguna con un yacimiento geotérmico o de anomalía termal. Los bajos valores de resistividad del primer intervalo se relacionan con la presencia de alteración hidrotermal ahí detectada.

g) Se confirma que la zona esta ubicada en un mínimo gravimétrico relacionada con una estructura tipo graben (NW-SE).

POZO CB-3.- Alcanzó una profundidad de 1911 m. Los resultados obtenidos para este pozo de acuerdo a los objetivos concluyen:

a) Que el aérea del Domo San Pedro-Tepeltitic, esta ubicada dentro de una zona anómala térmica. Quizás en relación al complejo dómico del Plioceno-Reciente.

b) No se corto secuencia andesítica basal de la SMO.

c) Se permitió establecer la columna litológica y actualizar el Modelo Geológico.

d) Hasta la fecha se han realizado mediciones de densidad, estando pendiente las determinaciones de susceptibilidad magnética, conductividad y de datación en los núcleos extraídos de la perforación.

e) Se ha establecido de forma parcial la distribución mineralógica hidrotermal y de paragénesis.

f) Que los valores de bajos resistivos de 5 a 30 Ohm-m, están relacionados con una zona anómala termal, en correlación al complejo dómico de 101,000 años.

g) La anomalía Bouguer regional, presenta un mínimo gravimétrico donde se emplazaron las formas dómicas.

6.6.- Evaluación del Potencial Geotérmico

La ubicación del Proyecto Ceboruco dentro de la Provincia de la Faja Volcánica Mexicana, está relacionada con aparatos efusivos recientes calco-alcalinos diferenciados, en adición a una región tectónicamente activa de interés geotérmico, en la cual se han perforado tres pozos profundos CB-1 (2801 m), CB-2 (1700 m) y CB-3 (1911 m) para la evaluación del potencial geotérmico en la zona.

Estos pozos fueron localizados en sectores de "anomalías de interés" en base a estudios geofísicos, y de caracteristicas geológico-estructurales presentes en los sistemas hidrotermales.

La paragénesis de los minerales hidrotermales indican en general que la evaluación para el pozo CB-1 es de bajo grado, por su temperatura de formación de 137°C a 2801 m. En base a los estudios de inclusiones fluidas en calcita se determinó una temperatura de formación der 22°C mas caliente que la temperatura estabilizada por el Método Horner (115°C). Los datos de temperatura a lo largo del pozo no tuvieron relación con las anomalías geofísicas de mínimos resistivos.

Con respecto al parámetro de permeabilidad, ya sea primaria o secundaria para alojar un yacimiento, este también es restringido, debido a las bajas perdidas de circulación reportadas en la perforación (1.2 a 1.3 m^3/h en el tramo de 2300 a 2800 m).

La mineralogía de alteración hidrotermal así como su paragénesis para el CB-2, reporta minerales de bajo grado que aparecen a partir de los 600 m, hasta el fondo (calcita, óxidos, pirita, calcopirita, clorita, cuarzo). La epidota como geotermoindicador apareció desde los 900 m. La presencia de turmalina indica actividad hidrotermal antigua. El registro de temperatura por el método Horner a los 1691 m reporta 105°C como máxima. Las anomalías de bajos resistivos no tienen relación directa con la termalidad, pero sí con los productos de alteración hidrotermal de baja temperatura.

En lo referente a las condiciones de permeabilidad en base a perdidas de fluidos de perforación está también es bastante restringida para alojar un yacimiento.

La mineralogía de alteración como su paragénesis hasta ahora encontrada en el CB-3, reporta minerales como cuarzo, calcita, clorita, pirita y óxidos a partir de los 500 m, así como de magnetita, epidota, sericita y arcillas desde los 900 m hasta el fondo del pozo. Los resultados microtérmicos de inclusiones fluidas en cuarzo, a partir de los 550 m a 1310 m, reportan rangos de temperatura de homogeneización (Th) promedio de 133.5 a 178°C. En los 1420 m se tomo el valor mínimo de Th de 176°C (aún que varia hasta los 234°C).

Los registros de 24 h de reposo, permiten determinar un gradiente termal del orden de 20°C promedio, mas frías que las obtenidas en laboratorio para las inclusiones fluidas. La última serie de registros de temperatura permite establecer, por el método Horner, una temperatura de formación de 198°C a los 1906 m.

Las condiciones de permeabilidad referidas a los reportes de perdidas de fluidos son bajas, sin embargo el índice de permeabilidad real se determinará cuando concluyan las actividades de labado del pozo, las pruebas de inyeción-recuperación, evaluación y desarrollo del pozo.

En base a los datos disponibles se considera que el Potencial Geotérmico de interés, en el proyecto Ceboruco, se encuentra en la zona del pozo CB-3, donde se comprobó que existe una relación de la anomalía de los mínimos resistivos con zonas de alteración hidrotermal y temperaturas en el orden de los 189.06°C a 1906 m en rocas intrusivas.

7.- CONCLUSIONES

- El Proyecto Ceboruco se ubica dentro de la Provincia de la Faja Volcánica Mexicana.

- *El basamento está constituido por una secuencia* sedimentaria, afectada por intrusiones graníticas-granodioríticas calco-alcalinas de un gran Batolíto Circumpacífico del Cretácico Superior al Terciario Inferior.

- Las dataciones en rocas volcánicas permiten establecer tres períodos de actividad ígnea:

  a) Andesitas, riolitas, ignimbritas del Terciario Inferior, que constituyen el Grupo Inferior Volcánico de la Sierra Madre Occidental (base). Con efectos de fallamiento, fracturamiento y de alteración hidrotermal.

  b) Riolitas, ignimbritas, tobas y basaltos calco-alcalinos del Grupo Superior Volcánico de la SMO. Del Oligoceno-Mioceno.

  c) Basaltos, riolitas, dacitas, andesitas, tobas y pumicíticas, principalmente de carácter calco-alcalino, en coexistencia con algunos alcalinos, propios de la formación de la provincia de la Faja Volcánica Mexicana, del Plioceno al Reciente.

- Existen tres patrones estructurales regionales NW-SE, N-S y NE-SW.

- Existe una diferenciación magmática acentuada a partir del Mioceno Superior al Reciente.

- Las edades radiométricas para los domos de la zona del Domo San Pedro son de 1.7 hasta los 0.101 Ma.

- El último evento efusivo proviene del Ceboruco, y data del siglo pasado (1870-1875).

- Las manifestaciones termales en la zona son manantiales de agua caliente (48°C) de fumarolas (92°C).

- La presencia de fumarolas (92°C) en suelos vaporizantes en el volcan Ceboruco, permiten asegurar la presencia de actividad volcánica.

- Los gases presentes en las fumarolas corresponden a las esperadas en un ambiente geotérmico.

- Solo dos manantiales son clorurados-sódicos. Con características de salmueras geotérmicas, altamente diluidas por aguas subterráneas mas someras de reciente infiltración.

- El geotermómetro de K-Mg, arroja temperaturas de formación por abajo de los 100°C.

- No se detectaron evidencias de algún yacimiento geotérmico, ni anomalía termal de interés comercial en los pozos CB-1 y CB-2; sin embargo, la estructura del Ceboruco cuenta aún con zonas de interés para continuar la exploración en ella.

- La zona de los Domos San Pedro-Los Ocotes, está situada en una zona de gradiente anómalo, relacionada quizá con la presencia del complejo dómico de edad Reciente.

- Los estudios de resistividad con SEV's y con SMT's, determinaron que los valores de baja resistividad menores de 10 Omh.m medianamente someros, atractivos a estudiar en el subsuelo, no tuvieron relación con anomalías térmicas de importancia para los pozos profundos CB-1 y CB-2. La respuesta encontrada está relacionada con los productos de alteración de baja temperatura.

- Los valores de baja resistividad de 5 a 30 Ohm-m, para la zona del CB-3, se relacionan con una anomalía térmica de interés, asociada con un sistema hidrotermal con temperaturas mayores de 200°C.

- Mediante el método gravimétrico se determinó el comportamiento estructural (NW-SE y NE-SW), definiendo depresiones y levantamientos, en la que se han emplazado el volcán Ceboruco y Domo de San Pedro.

- Magnéticamente también se definieron lineamientos NW-SE y NE-SW que se asocian a la geometría estructural, expuesta en el párrafo anterior.

- De forma regional eléctricamente se definieron tres sectores de mínimos resistivos los que se asociaron a zonas de alteración hidrotermal, ubicándose en éstos los pozos de gradiente, mediante los cuáles se obtuvieron valores de flujo de calor tres veces mayor al considerado para el Eje Neovolcánico, lo que sugirió la presencia de una descarga de calor de un sistema hidrotermal de alta temperatura, como lo ha demostrado el pozo CB-3.

- Con la termalidad obtenida en el CB-3, se confirma el potencial geotérmico en la región.

Agua Caliente (M40), P. del Río (M55) y Santa Isabel (M66) presentan concentraciones de boro mayores de 3 ppm lo que indica que su uso debe ser reservado para cultivos moderadamente sensibles al boro.

5.- PERFORACION DE POZOS EXPLORATORIOS

La conjunción de los trabajos técnicos determinaron la localización de 3 pozos profundos de 2000 m (Figura 3.9), determinarán la existencia de una o varias zonas anómalas termales relacionadas con un yacimiento geotérmico susceptible de ser aprovechado en la generación de energía eléctrica.

POZO CB-1.- Se perforó en la ladera sur al volcán Ceboruco, bajo las coordenadas X = 596,800, Y = 2'332,500, y Z = 1130 msnm. En una parcela que pertenece al Ejido del Marquesado, municipio de Ahucatlán.

POZO CB-2.- Se perforó a 18 km al poniente del CB-1, en las coordenadas X = 529,850 Y = 2'333,400 y Z = 850 msnm, en una parcela al ejido Amado Nervo, municipio de San Pedro Lagunillas.

POZO CB-3.- Se perforó a 3.4 km al noreste del Domo Central de San Pedro y a 9 km al nor-noreste del pozo CB-2, bajo las coordenadas X = 530,950, Y = 2'342,650 y Z = 1220 msnm. En una parcela del municipio de San Pedro Lagunillas.

5.1.- Argumentos Técnicos en la Selección de Sitios

Los argumentos técnicos empleados para la selección de los sitios a perforar fueron geoquímicos, geológicos y geofísicos. Para el caso del sitio del pozo CB-1, fue el determinar la presencia de un yacimiento geotérmico asociados al volcán Ceboruco. Con los estudios geoquímicos se muestrearon y analizaron los gases de las fumarolas y suelos calientes con temperaturas máximas de 92°C, de los cráteres del aparato volcánico del Ceboruco (Cinco bocas), arrojando como resultado bióxido de carbono, ácido sulfhídrico e hidrógeno en cantidades comparables a las encontradas en pozos geotérmicos de alta entalpía.

Con la aplicación de la geotermometría de fase gaseosa se calcularon temperaturas de fondo del orden de 267°C; el estudio de mercurio mostró porcentajes mayores a los obtenidos en alguna zona geotérmica del país.

Los estudios geológicos regional y detalle concluyeron que el edificio volcánico debe estar relacionado a profundidad con una cámara magmática apenas en proceso de enfriamiento, ya que su última erupción es histórica (1870 - 1875), y relacionado a una zona con un desarrollo tectónico importante.

Los levantamientos geofísicos con el método de MT, recomendaron el sitio tomando como base la suposición de que el conductivo intermedio por su forma y sus valores de resistividad ahí detectados, estuviesen asociados al yacimiento geotérmico; los estudios gravimétricos y aeromagnéticos arrojaron como resultados que las anomalías de mínimos ahí presentes se relacionan con una zona de interés geotérmico.

Para el sitio del pozo CB-2, los argumentos geoquímicos se tienen en el análisis de las manifestaciones termales de los valles de Tetitlán-Valle Verde y el de Amado Nervo. Constituidos por manantiales con temperaturas máximas de 48°C. Además los elementos detectados sugieren que son indicadores de actividad geotérmica. Las temperaturas estimadas con el geotermómetro de K-Mg van desde los 53 hasta 68°C; sin embargo esta estimación se ve restringida por la naturaleza secundaria de los manantiales.

Los estudios de caracter geológico se basan en el desarrollo vulcanológico de la zona donde se han emplazado una serie de domos de composición dacítica, riolítica y andesítica a partir del Cuaternario Inferior (1.7 Ma). Tales estructuras se encuentran alineadas en una dirección NW-SE, de una zona de debilidad que fue aprovechada para el ascenso y emplazamiento de las formas dómicas.

Los argumentos geofísicos (geoeléctricos y gravimetría), permitieron apoyar el sitio del CB-2 ya que el conductivo intermedio presenta valores de resistividades mínimos en esa zona que pudiesen estar relacionados con alta saturación o alteración hidrotermal, el análisis cualitativo de la anomalía de Bouguer detectó una zona de mínimo gravimétrico que es interpretada como una zona de graben o semigraben con orientación NW-SE.

Para el sitio del pozo CB-3, los estudios geoquímicos practicados a la manifestación de la Guásimas con 31°C, y la mas cercana al sitio, indican que tienen concentraciones de boro, sulfatos y cloruros como indicadores de actividad geotérmica.

Los estudios de caracter geológico apoyan el aérea debido que existe el emplazamiento de un complejo dómico calco-alcalino dacítico y riolítico con edades de 0.850 a 0.790 Ma, para el San Pedro hasta los 0.101 Ma, para el domo Los Ocotes. Orientados en una franja de debilidad NW-SE y N-S, en asociación con coladas mugearíticas, así como el de encontrar la andesita basal de la SMO.

Los estudios de geofísica eléctrica, arrojaron como resultado una correlación muy importante entre las anomalías de bajas resistividades con posibles zonas de fracturamiento o de calor. Además la anomalía de Bouguer regional presenta un mínimo gravimétrico en el área de los domos de San Pedro, que pudiera estar relacionada a una zona de depresión donde se emplazaron las formas dómicas recientes.

5.2.- OBJETIVOS

POZO CB-1.

a) Determinar la presencia de un yacimiento geotérmico asociado al Volcán Ceboruco.

b) Encontrar el yacimiento en la unidad basal andesítica de la Sierra Madre Occidental, Oligoceno-Mioceno, que debido a la intensa deformación compresiva se encuentra plegada, fallada, y fracturada produciendo una buena permeabilidad secundaria, constituyendo un acuífero de 600 - 700 m de espesor favorable para la exploración de un eventual yacimiento.

c) Comprobar el modelo geológico propuesto.

d) Conocer las características físicas de susceptibilidad magnética, densidad, conductividad en los núcleos extraídos durante la perforación. Además de su datación.

e) Establecer la distribución de la mineralogía hidrotermal así como de su paragénesis, y su relación con el vulcanismo del Ceboruco.

f) Determinar que caracteristicas de las rocas controlan las anomalías de baja resistividad obtenidas por el método magnetotelúrico, que por sus valores cualitativos menores de 10 Ohm.m, resultarían tener un interés geotérmico. Cuantitativamente se definieron a partir de los 400 m hasta los 1250 m.

Lo anterior se encuentra también sustentado en un comportamiento estructural del "basamento" en base al análisis de la información gravimétrica, que determina que el basamento se encuentra dentro de un mínimo gravimétrico interpretado como una depresión que sería alcanzado en el orden de los 1200 y 1300 m.

POZO CB-2

a) Determinar la presencia de un yacimiento geotérmico en el área de Amado Nervo.

b) Encontrar la base andesítica de la SMO.

c) Comprobar el modelo geológico para esta zona.

d) Conocer las características físicas de susceptibilidad magnética, densidad y conductividad en los núcleos extraídos durante la perforación. Además de su datación.

e) Establecer la distribución de la mineralogía hidrotermal así como su paragénesis en relación al vulcanismo dómico reciente de la zona.

f) Conocer las caracteristicas que determinan dos zonas de interés con valores de baja resistividad (5-10 Ohm.m) en el intervalo de los 900 a 1200 m, y por debajo de los 1500 m de profundidad.

g) Penetrar a una zona de mínimo gravimétrico relacionada con una estructura tipo graben paralela al sistema regional principal (NW-SE).

POZO CB-3

a) Determinar la presencia del un yacimiento geotérmico en el área de los Domos San Pedro-Los Ocotes.

b) Encontrar la base andesítica de la SMO.

c) Comprobar el modelo geológico para esta zona.

d) Conocer las características físicas de susceptibilidad magnética, densidad y conductividad en los núcleos extraídos de la perforación del pozo. Además de su datación.

e) Establecer la distribución de la mineralogía hidrotermal así como su paragénesis, y su relación con los domos recientes de 100 000 años de Los Ocotes y Los Lobos.

f) Atravezar la zona anómala de interés termal con valores de baja resistividad de 5 a 30 Ohm.m.

5.3.- RESULTADOS DE LA PERFORACION

El pozo CB-1, se inició a perforar el 6 de octubre de 1993 y concluyó el 23 de marzo de 1994. Alcanzó un desarrollo máximo de 2801 m de profundidad, con una temperatura máxima estabilizada de 115°C.

El pozo CB-2, se inició a perforar el 10 de abril de 1994 y concluye el 22 de julio de 1994. Este pozo tiene una profundidad de 1700 m.

El pozo CB-3, se inició a perforar el 18 de agosto de 1994 y concluyó el 5 de diciembre de 1994, con un desarrollo máximo de 1911 m.

5.4.- Terminación de Pozos

El estado mecánico de los pozos exploratorios profundos quedó de la siguiente manera:

POZO CB-1.- Se instaló con tubería de revestimiento (TR) de 9 5/8", de 0 a 1494.28 mbnt. De ahí con agujero descubierto de 8 1/2" hasta los 2801 m. El pozo presenta una obstrucción por derrumbe de 2160 m hasta la profundidad total (Figura 5.1). Durante la perforación se extrajeron 7 núcleos a diferentes profundidades.

POZO CB-2.- Quedo con TR de 13 3/8" de 0 a 303 mbnt, agujero descubierto de 12 1/4" hasta 1506 mbnt.; y agujero descubierto de 8 1/2" hasta 1700 mbnt (Figura 5.2).

POZO CB-3.- Tiene TR de 9 5/8 de 0 a 496 mbnt; y lleva agujero descubierto de 8 1/2" hasta 1911 m (Figura 5.3).

FIG. 5.1 REGISTRO CONTINUO DE PERFORACION

PROYECTO EL CEBORUCO

POZO : CB-1

X: 546 800
Y: 2 332 500
Z: 1130

FECHA DE INICIO: 06/10/1993
FECHA TERMINACION: 23/03/1994
PROFUNDIDAD: 2801 M.B.N.T.
TEMP. FONDO: 110.1 oC

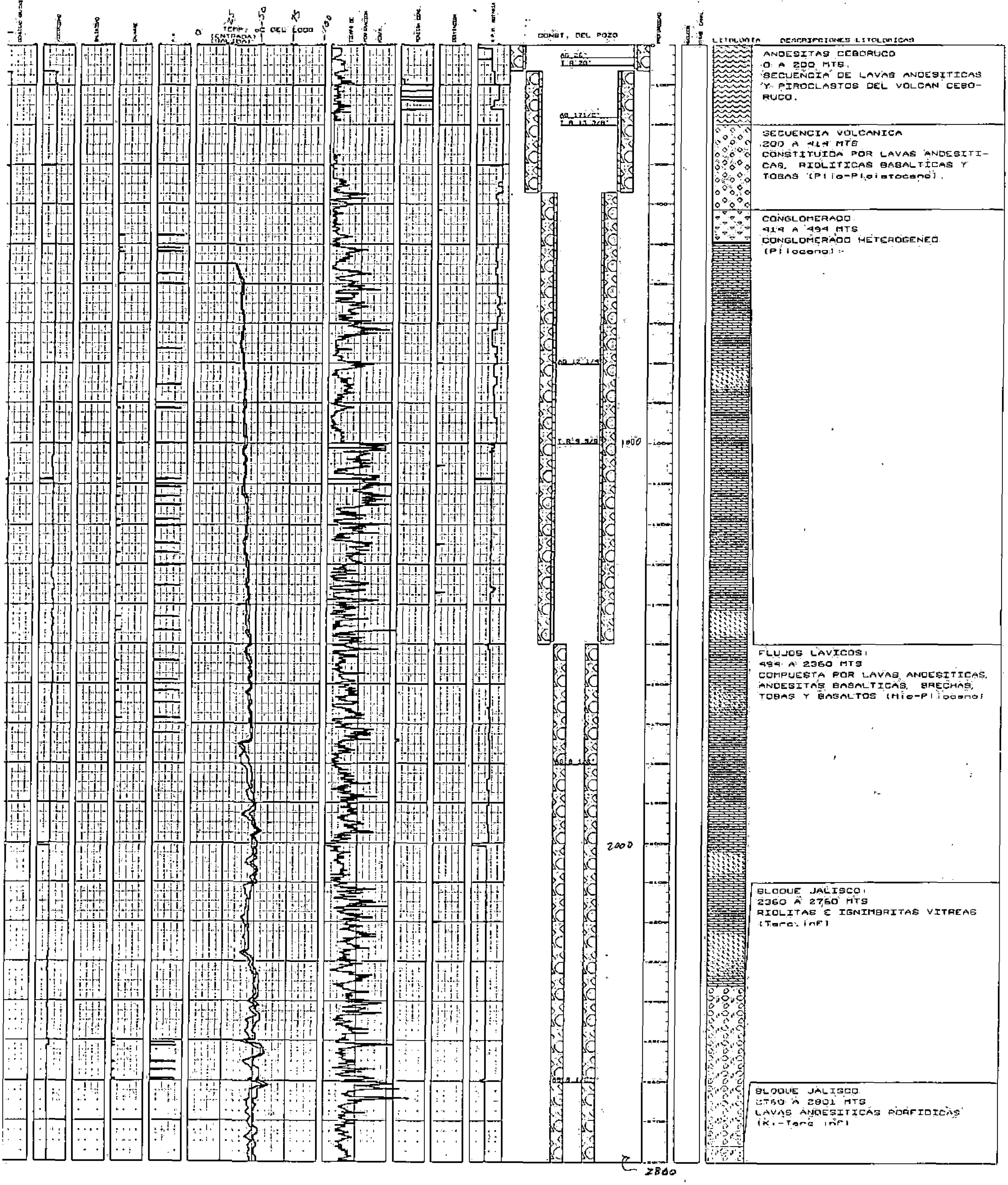


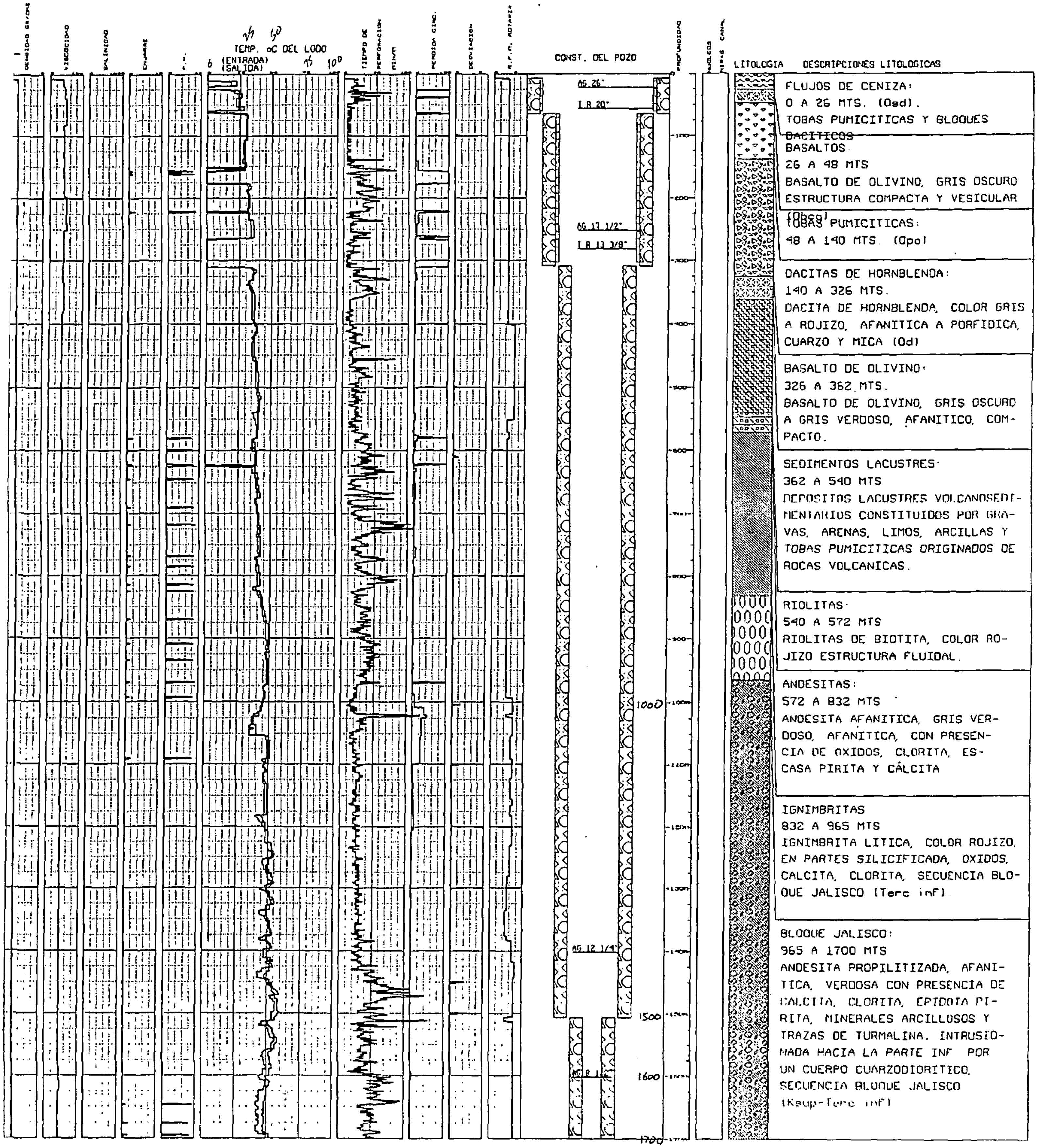
FIG. 5.2 REGISTRO CONTINUO DE PERFORACION

PROYECTO EL CEBORUCO

POZO : CB-2

X : 529 850
Y : Z 333 400
Z : 850

FECHA DE INICIO : 10/04/1994
FECHA TERMINACION : 22/07/1994
PROFUNDIDAD : 1700 M.B.N.T.
TEMP. FONDO : 105.4 oC



FLUJOS DE CENIZA:
0 A 26 MTS. (Oad).
TOBAS PUMICITICAS Y BLOQUES DACITICOS

BASALTOS
26 A 48 MTS
BASALTO DE OLIVINO, GRIS OSCURO ESTRUCTURA COMPACTA Y VESICULAR (Obco)

TOBAS PUMICITICAS:
48 A 140 MTS. (Opo)

DACITAS DE HORNBLENDA:
140 A 326 MTS.
DACITA DE HORNBLENDA, COLOR GRIS A ROJIZO, AFANITICA A PORFIDICA, CUARZO Y MICA (Od)

BASALTO DE OLIVINO:
326 A 362 MTS.
BASALTO DE OLIVINO, GRIS OSCURO A GRIS VERDOSO, AFANITICO, COMPACTO.

SEDIMENTOS LACUSTRES:
362 A 540 MTS
DEPOSITOS LACUSTRES VOLCANOSEDIMENTARIOS CONSTITUIDOS POR GRAVAS, ARENAS, LIMOS, ARCILLAS Y TOBAS PUMICITICAS ORIGINADOS DE ROCAS VOLCANICAS.

RIOLITAS:
540 A 572 MTS
RIOLITAS DE BIOTITA, COLOR ROJIZO ESTRUCTURA FLUIDAL.

ANDESITAS:
572 A 832 MTS
ANDESITA AFANITICA, GRIS VERDOSO, AFANITICA, CON PRESENCIA DE OXIDOS, CLORITA, ESCASA PIRITA Y CÁLCITA

IGNIMBRITAS
832 A 965 MTS
IGNIMBRITA LITICA, COLOR ROJIZO, EN PARTES SILICIFICADA, OXIDOS, CALCITA, CLORITA, SECUENCIA BLOQUE JALISCO (Terc inf).

BLOQUE JALISCO:
965 A 1700 MTS
ANDESITA PROPILITIZADA, AFANITICA, VERDOSA CON PRESENCIA DE CALCITA, CLORITA, EPIDOTA PIRITA, MINERALES ARCILLOSOS Y TRAZAS DE TURMALINA. INTRUSIONADA HACIA LA PARTE INF POR UN CUERPO CUARZODIORITICO, SECUENCIA BLOQUE JALISCO (Ksup-Terc inf)

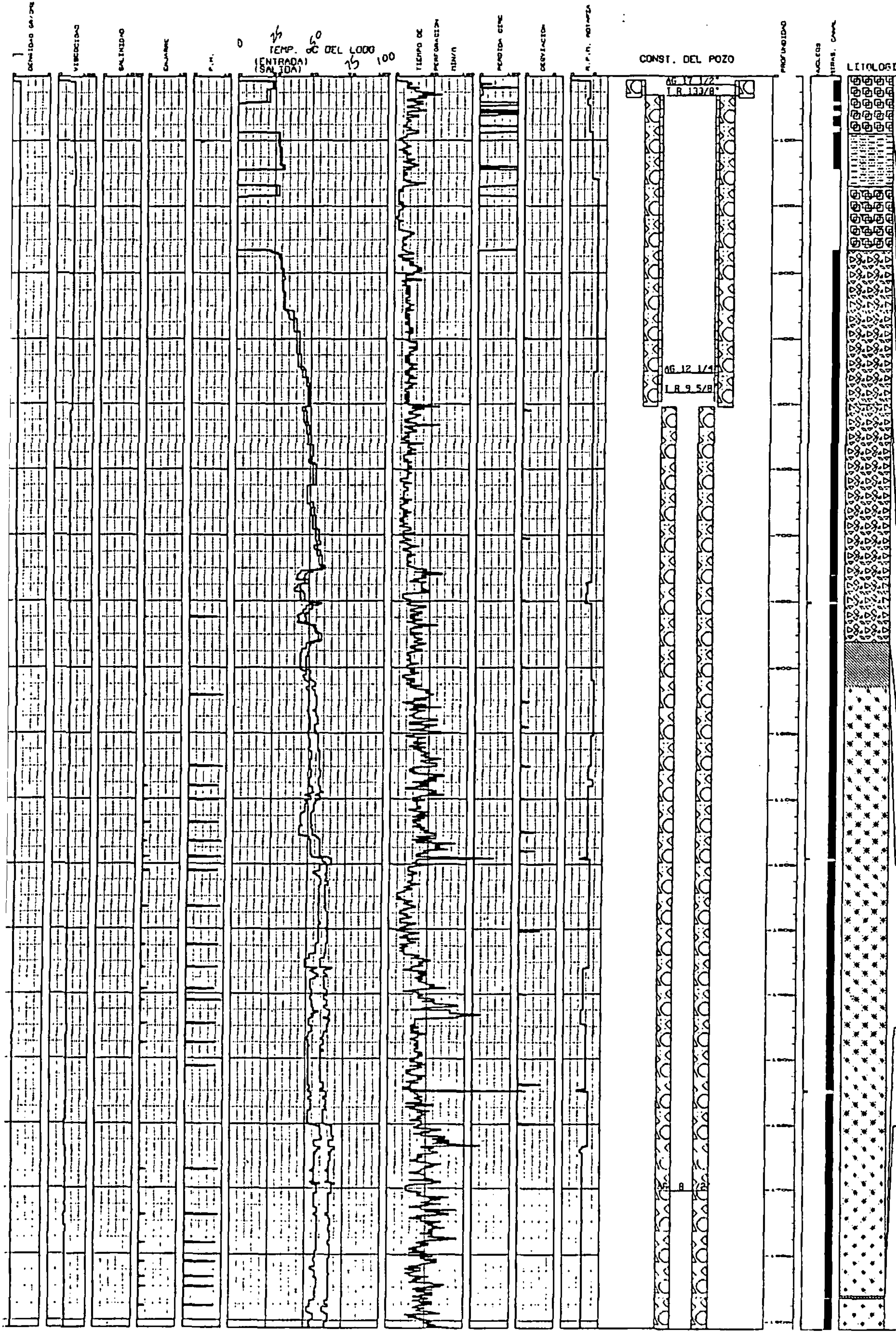
FIG. 5.3 REGISTRO CONTINUO DE PERFORACION

PROYECTO EL CEBORUCO

POZO : CB-3

X : 530 950
Y : 2 342 650
Z : 1220

FECHA DE INICIO : 18/08/94
FECHA TERMINACION : 05/12/94
PROFUNDIDAD : 1911 M.B.N.T.
TEMP. FONDO : 183.3 oC



RIOLITA VITREA:
DE 0 A 90 MTS.
RIOLITA VITREA CON ESTRUCTURA FLUIDAL COLOR GRIS CLARO A ROSASEO Y VIDRIO VOLCANICO

OBSIDIANA:
DE 90 A 170 MTS
VIDRIO VOLCANICO (OBSIDIANA) CON ESCASOS FRAGMENTOS RIOLITICOS

RIOLITA FLUIDAL
DE 170 A 266 MTS
RIOLITA VITREA GRIS ROJIZA CON ESTRUCTURA FLUIDAL

DACITAS SAN PEDRO
DE 266 A 500 MTS
DACITAS DE HORNBLENDA Y BIOTITA, GRIS CLARO TEXTURA PORFIDICA MESOSTASIS VITREA

DACITA HIDROTERMALIZADA
DE 500 A 860 MTS
DACITA DE HORNBLENDA Y MICA, ALTERADA Y MINERALIZADA COLOR BLANCO, GRIS VERDOSO Y ROJIZO, CON CUARZO, PIRITA, CALCITA, CLORITA, ARCILLAS Y OXIDOS.

ANDESITA:
DE 860 A 928 MTS
ANDESITA GRIS OBSCURO, MESOSTASIS VITREA, TEXTURA AFANITICA A MICROPORFIDICA CON CALCITA, PIRITA, CUARZO Y PROBABLE EPIDOTA.

GRANITO:
DE 928 A 1860 MTS
GRANITO DE BIOTITA Y PIROXENOS, COLORACION ROSACEA TEXTURA HOLOCRISTALINA GRANULAR, CON PRESENCIA DE CUARZO, CALCITA, CLORITA ARCILLAS, PIRITA Y TRAZAS DE EPIDOTA

ANDESITA CLORITIZADA:
DE 1860 A 1864 MTS
ANDESITA CLORITIZADA, CON VETILLAS DE EPIDOTA, PIRITA, CALCITA Y CUARZO

GRANITO
DE 1864 A 1911 MTS
GRANITO DE BIOTITA Y PIROXENOS, COLORACION ROSACEA TEXTURA HOLOCRISTALINA GRANULAR, CON PRESENCIA DE CUARZO, CALCITA, CLORITAARCILLAS, PIRITA Y TRAZAS DE EPIDOTA

equipo Kuster, en diferentes intervalos de profundidad como a diversos intervalos de tiempo, segun se exibe a continuación.

REGISTROS DE TEMPERATURA EN EL POZO CB-1

REGISTROS	HORAS DE REPOSO	TEMPERATURA MAXIMA	INTERVALO DEL REGISTRO
T-5	12	34.00°C	0 a 495 m
T-7	12	50.71°C	0 a 994 m
T-12	20	65.80°C	900 a 1494 m
T-18	25	90.00°C	1000 a 1987 m
T-21	24	96.20°C	1500 a 2481 m
T-25	24	102.70°C	0 a 2583 m
T-27	18	110.10°C	2000 a 2785 m

La temperatura máxima estabilizada por el método Horner fue de 115 °C a los 2801 m (gradiente termal normal).

$\frac{110-20}{2785} = 32.3$ °C

$\frac{115-20}{2801} = 33.9$ °C/Km

REGISTROS DE TEMPERATURA EN EL POZO CB-2

REGISTRO	HORAS DE REPOSO	TEMPERATURA MAXIMA	INTERVALO DEL REGISTRO
T-3	18	52.0°C	0 a 660 m
T-6	18	77.8°C	500 a 1050 m
T-9	18	92.3°C	800 a 1500 m
T-13	24	105.4°C	900 a 1691 m

La temperatura máxima estabilizada por paquete TEMPEST es de 111.87°C (gradiente termal normal ligeramente anómalo).

$\frac{105-20}{1691} = 50.3$ °C/Km

$\frac{111.87}{1691} = 54.3$ °C/Km

REGISTROS DE TEMPERATURA EN EL POZO CB-3

REGISTROS	HORAS DE REPOSO	TEMPERATURA MAXIMA	INTERVALO DEL REGISTRO
T-4	24	127.5°C	0 a 791 m
T-8	24	156°C	450 a 1186 m
T-11	18	171.5°C	450 a 1420 m
T-15	24	183.3°C	0 a 1906 m

La temperatura máxima estabilizada por el método Horner a los 1906 m es de 198°C. (gradiente termal anómalo).

$\frac{183.3-20}{1906} = 85.7$

$\frac{198}{1906} = 93.4$ °C/Km