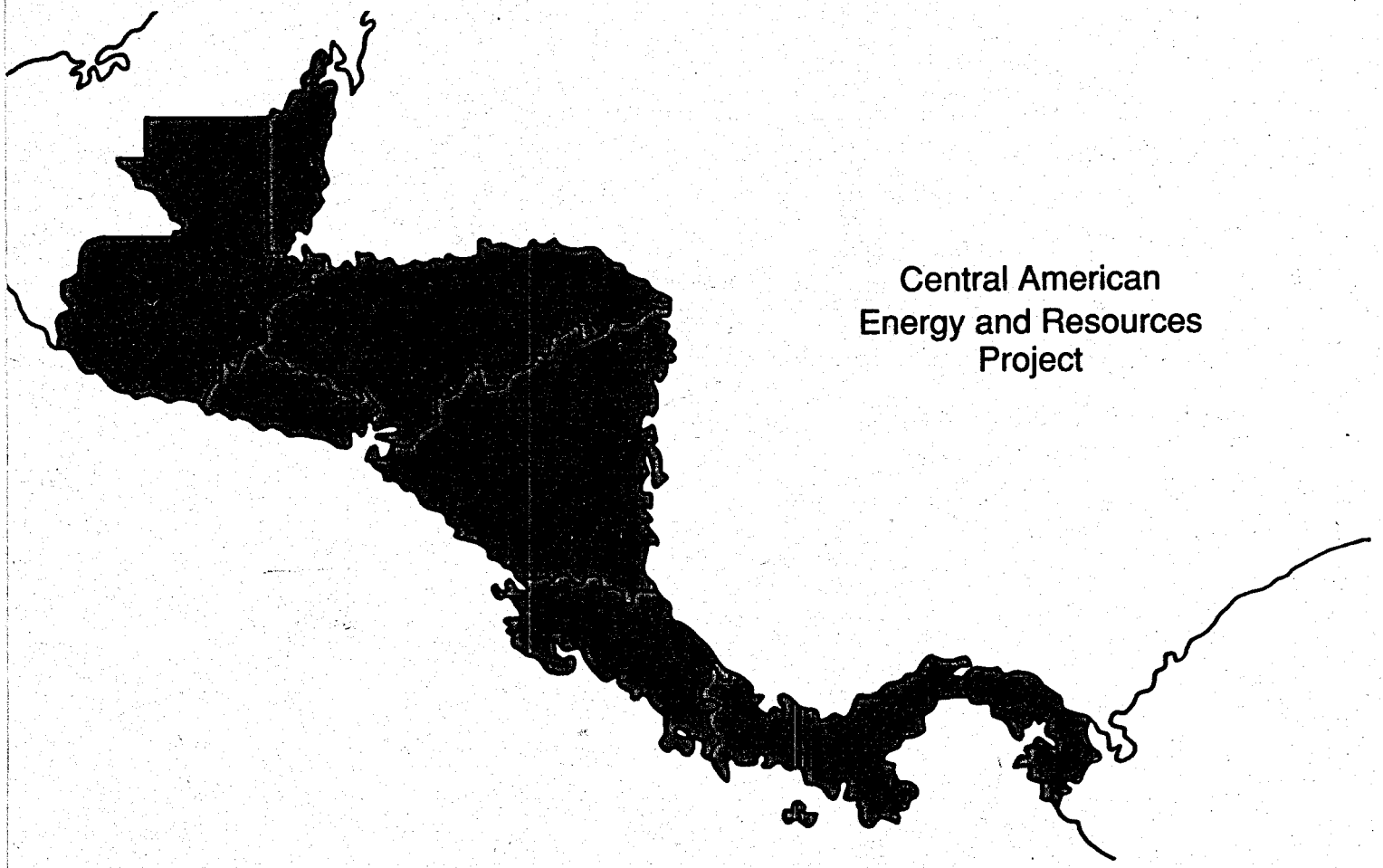
Received by OSTI
DEC 0 8 1988

LA-11410-MS

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.



Central American
Energy and Resources
Project

Recommendations Report for the Platanares Geothermal Site, Department of Copán, Honduras

REPRODUCED FROM
BEST AVAILABLE COPY

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Translated by Manuel Pérez, Clara Chávez, Mable Amador, and Yvonne Keller

This work was supported by the U.S. Agency for International Development.

An Affirmative Action/Equal Opportunity Employer

REPRODUCED FROM
BEST AVAILABLE COPY

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LA-11410-MS

UC-000
Issued: November 1988

Recommendations Report for the Platanares Geothermal Site, Department of Copán, Honduras

The Los Alamos National Laboratory and U.S. Geological Survey Geothermal Assessment Team
A. W. Laughlin, Project Leader

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

EXECUTIVE SUMMARY

Reconnaissance and detailed geothermal investigations have identified Platanares, Copán, as the highest-potential geothermal site in Honduras. Beginning with six known geothermal areas, a team comprising geoscientists from the Empresa Nacional de Energía Eléctrica (ENEE), the Los Alamos National Laboratory (Los Alamos), and the U.S. Geological Survey (USGS) used a variety of reconnaissance assessment techniques to rank the potential of the six sites. Particular emphasis was placed on the use of geothermometry to estimate subsurface reservoir temperatures. The two sites with the lowest reservoir temperatures were eliminated from further study; more costly detailed geological and geochemical investigations were conducted at the four remaining sites. These investigations eliminated one other site, leaving Platanares, San Ignacio, and Azacualpa for additional work.

Because of time and financial constraints, Los Alamos, the USGS, and ENEE concentrated their efforts at Platanares and San Ignacio while an Italian/ENEE team funded by the United Nations Development Program (UNDP) performed additional detailed studies at San Ignacio and Azacualpa. The Los Alamos/USGS/ENEE team conducted detailed geophysical surveys at Platanares and San Ignacio and drilled three geothermal gradient coreholes at Platanares. A preliminary economic study of the Platanares geothermal site was also conducted by Los Alamos and ENEE. The results of reconnaissance and detailed investigations of the Platanares site are summarized below.

Location. The Platanares geothermal site is located in the Department of Copán in west-central Honduras. It is approximately 16 km west of Santa Rosa de Copán.

Geology. Tertiary age silicic tuffs and andesite flows overlie the Cretaceous Valle de Angeles red beds. In addition to the northwest-trending Quebrada del Agua Caliente fault, many other faults in the area have apparently controlled the movement of ascending hot water.

Surface Geothermal Manifestations. Most of the hot springs and all of the boiling springs occur along a northwest-trending fault coincident with the Quebrada del Agua Caliente. The waters are alkaline-chloride in nature, and their chemical and isotopic compositions indicate that they equilibrated with red beds of the Valle de Angeles Group at temperatures of 225°-240°C. The surface hot springs discharge approximately 3400 ℓ/min.

Geophysics. Detailed gravity and electrical surveys confirm the location of the major faults at the site. The electrical survey also shows a promising low-resistivity anomaly along the Rio Lara west of the Quebrada del Agua Caliente.

Heat Source. The Tertiary age (14.5 Ma) of the volcanic rocks indicates that they are too old to be the heat source and that the heat source is non-volcanic. Therefore, the high subsurface temperatures must result from deep circulation of water in a region of thin, extended crust.

Drilling Results. High flow rates (up to 515 ℓ/min) of 160°-165°C water were encountered at depths as shallow as 250 m in two of the three gradient coreholes. A conductive geothermal gradient of 139°C/km was measured in the remaining hole. The drilling results suggest that there are two reservoirs at Platanares: a shallow 160°-165°C reservoir and a deeper 225°-240°C reservoir. Extrapolation of the 139°C gradient suggests that the deeper reservoir lies at a depth of 1200-1500 m. At maximum flow the flowing pressure was 70 psia. The two small-diameter (7.8 cm) flowing wells produce 3 and 4.4 MW (thermal), respectively.

Economics. A preliminary study investigated the economics of developing 10 MW from the shallow reservoir. Benefits outweighed the present value of costs by a factor of more than 3 to 1. The total value of benefits was calculated by summing the cost reduction of installing a geothermal plant instead of a hydroelectric plant and the value of electricity generated over the 18-year study period.

A panel consisting of staff from Los Alamos, the USGS, and ENEE, plus a geothermal consultant employed by Los Alamos, evaluated all of the data and developed a recommendations report for future work at Platanares. Their recommendations are summarized below.

1. Both the shallow and deep reservoirs require further assessment and testing.

2. Six production diameter wells should be drilled into the shallow reservoir to allow testing and production of 10 MWe while funding is sought for deep testing.

3. Three additional coreholes should be drilled to define the boundaries of the system.

4. A 2000-m production diameter well should be drilled to locate and test the deep reservoir.

5. A second 2000-m well should be drilled to confirm these results.

6. Supporting geological, geochemical, and geophysical investigations should be conducted to refine the conceptual model of the Platanares geothermal system and improve the understanding of the subsurface conditions.

RECOMMENDATIONS REPORT FOR THE PLATANARES GEOTHERMAL SITE, DEPARTMENT OF COPAN, HONDURAS

by

The Los Alamos National Laboratory and U.S. Geological Survey
Geothermal Assessment Team

A. W. Laughlin, Project Leader

ABSTRACT

A geothermal assessment of six previously identified sites in Honduras has been conducted by a team comprised of staff from the Los Alamos National Laboratory, the U.S. Geological Survey, and the Empresa Nacional de Energía Eléctrica. The application of both reconnaissance and detailed scale techniques lead to the selection of Platanares in the Department of Copán as the highest potential site. Additional work resulted in the completion of a prefeasibility study at Platanares.

We present here a tabulation of the work completed and short summaries of the results from these technical studies. We also present a brief model of the geothermal system and recommendations for additional feasibility work.

I. INTRODUCTION

In 1985, the Los Alamos National Laboratory (Los Alamos) began a cooperative effort with the Empresa Nacional de Energía Eléctrica (ENEE) and the U.S. Geological Survey (USGS) to assess the geothermal potential of Honduras. The objectives of the program, as originally designed, were to determine the relative potential of six previously identified geothermal areas

and to complete a country-wide assessment of Honduras. Because of time and funding constraints, however, emphasis was placed on the assessment of the six known geothermal areas: Platanares, San Ignacio, Azacualpa, Pavana, El Olivar, and Sambo Creek.

Reconnaissance-scale assessment techniques were used at all six areas and, based primarily on geothermometric estimates of reservoir temperatures, El Olivar and Sambo Creek were eliminated from further consideration at this time. Detailed geological and geochemical investigations were performed at the four remaining areas and led to the selection of Platanares as the highest-ranked potential site. San Ignacio and Azacualpa appeared to have approximately equal but slightly lower potential. Detailed gravity and self-potential surveys were conducted at Platanares and San Ignacio, and three geothermal gradient coreholes were drilled at Platanares. Because of the encouraging results at Platanares, additional detailed structural mapping was done. An AMT/MT survey was conducted by the USGS and ENEE, and an economics study was performed by Los Alamos and ENEE.

A tabulation of the prefeasibility geothermal assessment work completed at Platanares is given in Section II. Results of the numerous investigations have been evaluated, and a model of the Platanares geothermal system has been developed. We present this model in this report with recommendations for future work at Platanares. Estimates of drilling costs for the several drilling options are also provided. Summaries of the results of the geological, geochemical, and geophysical investigations and of the drilling are presented as Appendices A-G.

II. TABULATION OF GEOTHERMAL WORK COMPLETED TO DATE IN HONDURAS BY THE ENEE/ LOS ALAMOS/USGS TEAM

A. Country-Wide Geothermal Assessment

1. Water geochemistry on spring and stream samples.
2. Compilation of a catalog of hot springs and thermal place names.
3. Generation of a new gravity map of Honduras.
4. Reprocessing of aeromagnetic data from Honduras.

B. Site-Specific Geothermal Investigations

1. Reconnaissance-scale geologic investigations at six previously identified geothermal areas: Sambo Creek, El Olivar, Pavana, Azacualpa, San Ignacio, and Platanares.
2. Reconnaissance-scale geochemical investigations at the same six previously identified geothermal areas.
3. Detailed geologic investigations at four geothermal areas: Pavana, Azacualpa, San Ignacio, and Platanares.
4. Detailed hydrogeochemical investigations at three geothermal areas: Azacualpa, San Ignacio, and Platanares.
5. Detailed gravity and self-potential surveys at two geothermal areas: San Ignacio and Platanares.
6. Intermediate-depth geothermal gradient coring at Platanares geothermal area. Three coreholes completed.
7. Temperature measurements in these three coreholes.
8. Detailed geologic study of samples from the three coreholes, including lithology, fluid inclusions, and hydrothermal mineralogy.
9. Pressure, temperature, and flow rates determined for the three coreholes.
10. Geothermal reservoir residence times and fluid volumes calculated.
11. Detailed structural geologic mapping performed at Platanares.
12. AMT/MT survey conducted at Platanares.
13. Economics study of Platanares completed.

III. THE CONCEPTUAL MODEL OF THE PLATANARES GEOTHERMAL SYSTEM

The Platanares geothermal system is similar to the Basin and Range type geothermal systems of the western United States. The heat source is non-magmatic; instead, the water is heated during deep circulation in a region of thin, hot, extended crust. The Platanares geothermal system comprises two reservoirs: a shallow 160°-165°C reservoir and a deeper 225°-240°C reservoir. It is not yet known if these reservoirs are stacked or comprise a continuum.

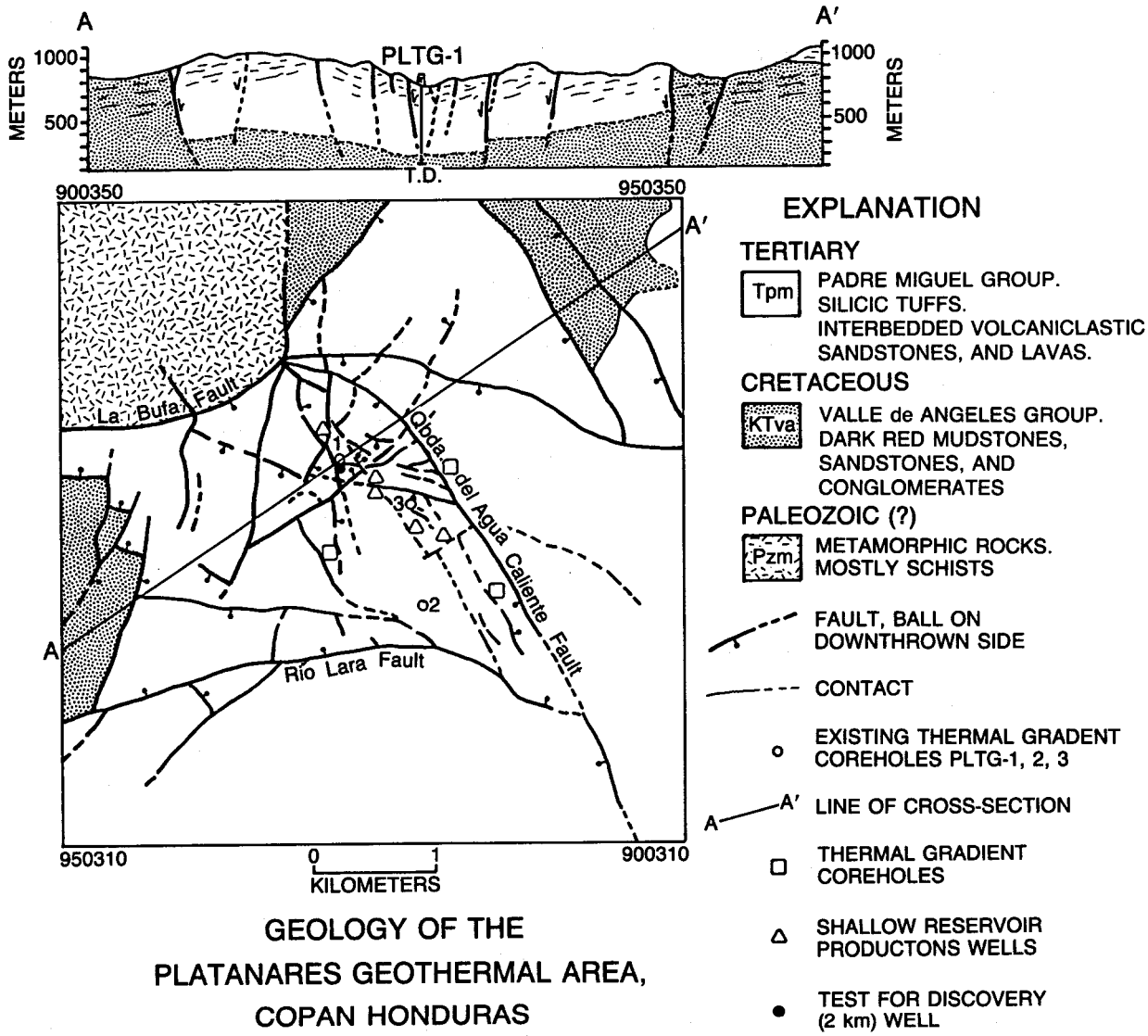
Surface manifestations of the Platanares geothermal system occur within a 3.2-km^2 area surrounding the northwest-trending Quebrada del Agua Caliente. The distribution of these manifestations indicates that the near-surface flow

of hot water is controlled by the large northwest-trending fault zone coincident with the Quebrada del Agua Caliente and several smaller east to northeast-trending faults. Additionally, low-angle normal faults allow hot water to flow significant horizontal distances. The system is water-dominated, and the chemistry of water and gas samples from the hot springs indicates that the water equilibrated within red beds of the Valle de Angeles Group is at a temperature of 225°-240°C. Extrapolation of the geothermal gradient measured in the second corehole, PLTG-2, suggests that this temperature occurs at a depth of about 1.5 km in the deeper reservoir. Superheated water at a temperature of 160°-165°C encountered in the coreholes at a depth of about 250 m may originate from leakage and convection from this deeper, higher-temperature reservoir. Flow tests conducted on PLTG-1 indicate that this well taps 0.06 km^3 of 160°-165°C water within the shallow reservoir. Flow rates of up to 440 ℓ/min were measured from the shallow, 160°-165°C reservoir. Considering the temperature, flow rates, permeability, and probable fluid volumes, development of this reservoir using binary-cycle generators appears feasible.

Although the depth, exact location, volume, and flow rates of the high-temperature reservoir have not been determined, its apparent temperature of 225°-240°C makes it a potential target for further investigation.

IV. RECOMMENDATIONS

1. Because of the continued encouraging results, feasibility stage assessment should be initiated at the Platanares geothermal site, Honduras, as soon as possible.
2. To most efficiently meet ENEE's need for increased generating capacity by 1992-1993, further assessment and testing should be performed of both the shallow and deep geothermal reservoirs at Platanares.
3. Immediate funding should be sought for drilling two production diameter wells at Platanares: 1) a test for discovery (TFD) well and 2) a confirmation well. Depths of approximately 2 km should be planned for these wells. A tentative site for the TFD well is shown on Fig. 1. Requested funding should be sufficient to allow drilling three additional



GEOLOGY OF THE
PLATANARES GEOTHERMAL AREA,
COPAN HONDURAS

Figure 1. Geologic map of the Platanares geothermal site showing recommended drill sites.

geothermal gradient coreholes for better definition of the boundaries of the geothermal system. Proposed locations for these gradient coreholes are also shown on Fig. 1.

4. While funding is sought for the deeper, more expensive wells, five production diameter wells should be drilled into the shallow 160°-165°C

reservoir at the sites shown on Fig. 1. If results are positive, these wells can be used as production and reinjection wells for developing the shallow reservoir with portable, staged, binary-cycle generators. If results are negative, data recovered will still be of value in refining the location of the TDF well.

5. Supporting geological, geochemical, and geophysical investigations should continue in order to refine the conceptual model and improve the understanding of subsurface conditions at the Platanares site. Much of this work should be done by ENEE staff with technical support from Los Alamos and the USGS where necessary. These investigations should focus on further delineating the boundaries and depths of the two geothermal reservoirs (by geologic mapping and gradient drilling), improving the characterization of the fracture permeability, and improving the estimates of flow rates and reservoir volumes.

V. ESTIMATES OF DRILLING COSTS

Type	Number	Estimated Cost ($K)
500-m production diameter wells	5	3000
500-m gradient wells	3	660
2000-m TFD well	1	1500
2000-m confirmation well	1	1400

APPENDIX A

SUMMARY OF THE GEOLOGY OF THE PLATANARES GEOTHERMAL AREA, COPAN, HONDURAS

Grant Heiken, Kenneth Wohletz, and Dean Eppler
Los Alamos National Laboratory

Wendell Duffield and Sue Priest
U.S. Geological Survey

Napoleón Ramos, Wilmer Flores, and Carlos Escobar
Empresa Nacional de Energía Eléctrica

Alexander Ritchie
College of Charleston

INTRODUCTION

The Platanares geothermal area in the Department of Copán is located in west-central Honduras, about 30 km from the Guatemalan border (Fig. A-1). Many boiling springs are present in the area, most of which occur along the Quebrada del Agua Caliente. These thermal manifestations have prompted several geothermal investigations (Flores, 1980; Heiken et al., 1986; Goff et al., 1987), the most recent of which is our current program of geology, geophysics, hydrogeochemistry, and drilling. Geologic studies have produced a geologic map of about 25 km^2 of the Platanares area, radiometric-age determinations for the volcanic rocks, and lithologic and geochemical studies of cores from the wells.

STRATIGRAPHY

The oldest rocks in the area are Paleozoic(?)-age schists, phyllites, and quartzites, which form a highland north of the thermal area. Contacts between

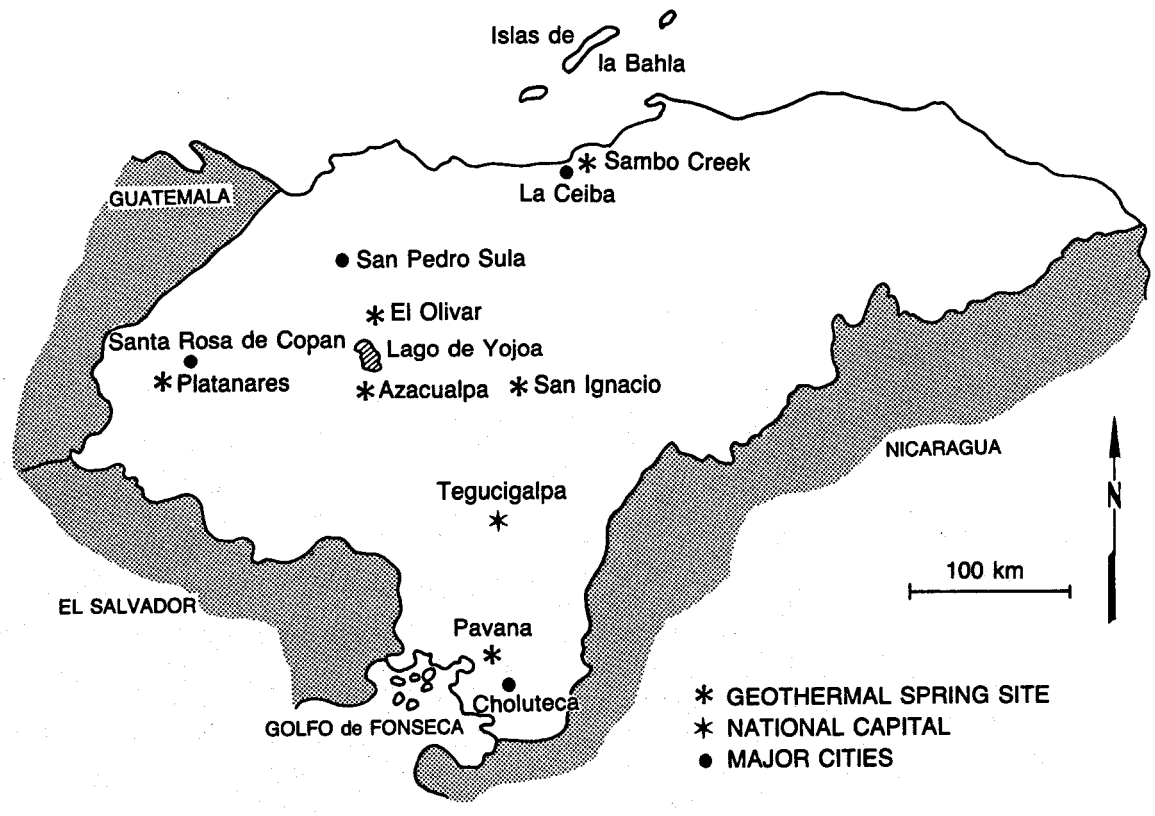


Figure A-1. Location map of the Platanares geothermal site.

metamorphic rocks and the younger Cretaceous and Tertiary rocks are faults. The metamorphic rocks form a high mountainous terrain along the northern and northwestern margins of the geothermal area, and this highland apparently has been a major source of metamorphic clasts found in Cretaceous and Tertiary sedimentary and pyroclastic units. Stream and terrace gravels within the Quebrada del Agua Caliente also are composed of mostly metamorphic clasts.

The next younger unit is a red bed sequence, the Valle de Angeles Group of Cretaceous age. At Platanares, this Group consists of moderately to poorly bedded siltstone, pebbly coarse sandstone, coarse immature sandstone, and conglomerate. Most of the rocks are red, but locally the color is pale green or tan where hydrothermally altered. The total thickness of red beds in this area is not known but is minimally 200 m; elsewhere in Honduras it can reach thicknesses of 3300 m (Mills et al., 1967). Coarser clastic rocks from this Group consist of a mixture of basaltic and metamorphic clasts. Chemical characteristics of the thermal waters suggest that these red beds may be the main reservoir rock (Goff et al., 1987).

Discontinuous stacks of andesitic lava flows overlie the red beds of the Valle de Angeles Group. Within the Platanares area, they crop out along the streambed of the Quebrada del Agua Caliente, immediately north of well PLTG-1 and are penetrated by PLTG-1 and PLTG-3, where they are 550 m and 250 m thick, respectively. These lavas were not intersected by PLTG-2 but may be below the bottom of that well. They are believed to correlate with the Matagalpa Formation, an Eocene-Oligocene unit characterized by mostly andesitic lavas and unconformably overlain by clastic rocks of the Subinal Formation and silicic tuffs of the Padre Miguel Group (Williams and McBirney, 1969; Finch, 1981). At Platanares, all of these andesitic lavas are hydrothermally altered.

Separating the Matagalpa Formation and the silicic tuffs of the Padre Miguel Group is an ~100-m-thick sequence of red beds. These consist of dark red mudstones, sandy mudstones, and sandstones that may be correlative with the Subinal Formation defined by Hirschmann (1963) in nearby Guatemala. Locally, the sandstones within these red beds are characterized by clasts derived entirely from metaquartzite and schist; this is in contrast with sandstones of the older Valle de Angeles Group, which contain a large volcanic clast component.

The youngest Tertiary rock unit is called the Padre Miguel Group and consists of mostly pyroclastic rocks, including massive nonwelded and welded rhyolitic tuffs, pumice fall deposits, and interbedded volcaniclastic sandstones. The thickness is highly variable in the Platanares area, reaching a maximum of 700 m. The most voluminous volcanic rocks are silicic pyroclastic flows, characterized by fine ash matrix with a few to several percent of lithic and pumice clasts that rarely exceed 5 cm in diameter. Individual flows are many meters thick, although contacts between flows are usually obscure. Other tuffs include pumice falls and surge deposits. Locally, thin red beds are interbedded with the tuffs. Padre Miguel rocks elsewhere range in age from 5 to 17 m.y. (Williams and McBirney, 1969; Eppler et al., 1987). Welded tuff samples collected from near the base of the Group have been dated at 14.7 ± 0.5 Ma and 14.2 ± 0.5 Ma (K-Ar biotite ages; analyzed by T. McKee, USGS). Vents for the volcanic rocks have not been identified. The pyroclastic flows may be from the Montaña de Celaque, which is possibly a large resurgent caldera, located 30 km south of the site. The tuffs and lavas are silicified near many faults and in corehole PLTG-1.

Stream terrace gravels form an irregular wedge, up to 60 m thick, along the boundary of the main spring area, near the confluence with the Río Higuito.

STRUCTURE

Stratification in the volcanic rocks dips 15° to 30° to the south or southwest; attitudes diverge from this regional dip near faults and landslides. Bedding in the red beds is generally to the south or southwest, with dips of 15° to vertical.

The Platanares area is highly disrupted by normal faults over an area of about 5 km^2. The Padre Miguel Group of volcanic rocks is downfaulted against Cretaceous red beds on the northeast and southwest, thus defining a northwest-trending graben. The graben is terminated on the north by a northeast-trending fault that places Paleozoic(?) metamorphic rocks and Cretaceous red beds against the younger volcanic sequence. To the southeast, outcrops of Tertiary volcanic rocks are continuous to the Montaña de Celaque, 30 km from Platanares.

Most of the thermal springs and all of the boiling springs are located along a northwest-trending fault zone that bisects the graben; the Quebrada del Agua Caliente is eroded along this fault zone. Many of these springs are depositing silica sinter that locally cements stream gravels to form resistant beds and banks. Inactive sinter terraces are present at several locations along the Quebrada, some as much as 20 m above the present stream. Two warm springs and several seeps are located about 1.5 km southwest of the main thermal area, along the east-west-trending faults that coincide with the drainage of the Río Lara. No thermal manifestations are known north of the fault termination at the north end of the graben or south of the Río Lara.

The main trace of the fault zone along the Quebrada del Agua Caliente has strong physiographic expression, including escarpments in river-terrace gravels near the confluence with the Río Higuito. A zone, 0.5 km wide, to the west of this main trace is complexly and highly faulted. The fault that coincides with the Río Lara is part of an east-west zone of strong lineation that is readily apparent on satellite images and extends well beyond the project area both to the east and west. Río Higuito makes a right-angled turn at its confluence with the Quebrada del Agua Caliente and follows this zone to the east. Well PLTG-2 is located about 200 m north of the main trace of this zone; abundant shears and clastic dikes seen in core from this hole may reflect its proximity to the Río Lara fault. Similarly, highly fractured core from PLTG-1, located along the Quebrada del Agua Caliente, reflects the degree of faulting there.

CONCLUSIONS

The geologic framework of the Platanares area consists of a basement sequence of highly deformed Paleozoic(?) metamorphic rocks that are overlain by Cretaceous red beds and Tertiary volcanic and sedimentary rocks. Although the maximum age of the volcanic sequence is not yet known, the degree of weathering, erosion, and faulting suggests that these rocks are too old to reflect the presence of an underlying magma reservoir in the crust. Thermal manifestations are localized along faults that cut the entire bedrock section, and thus the general geothermal character is somewhat akin to a typical hydrothermal system of the Basin and Range province of the United States.

The principal reservoir for the Platanares geothermal system is believed to be within red beds of the Cretaceous Valle de Angeles Group, the top of which is at least 400-600 m beneath the surface cover of Tertiary volcanic rocks and younger river-terrace gravels. Reservoir permeability is interpreted as fracture permeability as observed in coreholes PLTG-1 and PLTG-3, caused by fracturing along major fault zones. Geothermometry applied to the thermal water suggests a source reservoir temperature of 225°-240°C (Goff et al., 1987). The thermal water is likely heated during deep circulation in an environment of high crustal heat flow. The three recently drilled coreholes also hold promise of a shallow commercial-grade resource (160°-165°C) at Platanares.

REFERENCES

Eppler, D. B., Heiken, G., Wohletz, K., Flores, W., Paredes, J. R., and Duffield, W. A., 1987, Geology of the Pavana geothermal area, Departamento de Choluteca, Honduras, Central America, Los Alamos National Laboratory report LA-10864-MS, 17 pp.

Finch, R., 1981, Mesozoic stratigraphy of Central Honduras, Amer. Assoc. Petrol. Geol., v. 65, pp. 1320-1333.

Flores, W., 1980, Geology of the Platanares area, in Report of the activities and interpretation of results of the geothermal project of Honduras 1979-1980: Energy Programme of the Central American Isthmus, RLA/76/012.

Goff, F., Truesdell, A., Grigsby, C., Janik, C., Shevenell, L., and others, 1987a, Hydrogeochemical investigations of six geothermal sites in Honduras, Central America, Los Alamos National Laboratory report LA-10785-MS, 170 pp.

Heiken, G., Eppler, D., Wohletz, K., Flores, W., Ramos, N., and Ritchie, A., 1986, Geology of the Platanares geothermal site, Copán, Honduras, Los Alamos National Laboratory report LA-10634-MS.

Hirschmann, T., 1963, Reconnaissance geology and stratigraphy of the Subinal Formation (Tertiary) of the El Progreso area, Guatemala, Central America, Unpub. M.A. Thesis, Indiana University, 67 pp.

Mills, R., Hugh, K. E., Feray, D. E., and Swolfs, H. C., 1967, Mesozoic stratigraphy of Honduras, Bull. Amer. Assoc. Petrol. Geol., v. 51, pp. 1711-1786.

Williams, H., and McBirney, A., 1969, Volcanic history of Honduras, University of California Publ. Geol. Sci., v. 85, pp. 1-101.

APPENDIX B

SUMMARY OF THE HYDROGEOCHEMISTRY OF THE PLATANARES GEOTHERMAL AREA, COPAN, HONDURAS

Fraser Goff
Los Alamos National Laboratory

Detailed hydrogeochemical investigations were conducted at the six most promising geothermal sites in Honduras: Platanares, San Ignacio, Azacualpa, Pavana, Sambo Creek, and El Olivar (Goff et al., 1987a). In addition, a regional survey was made of the chemistry, stable isotopes, and tritium content of cold (background) waters. None of the geothermal sites are associated with Quaternary (≤1.8 My) silicic volcanism, although the El Olivar site lies adjacent to a small Quaternary basalt field, and Pavana is part of a belt of hot spring activity parallel to and 35 km east of the Central American volcanic arc. None of the sites contain acid-sulfate waters indicative of vapor-dominated conditions. Thermal waters at all sites are alkaline-chloride in character. Based on various types of chemical geothermometers, the three best geothermal prospects in Honduras have maximum subsurface reservoir temperatures of 225°C (Platanares), 190°C (San Ignacio), and 185°C (Azacualpa). Based on discharge rates and the estimated reservoir temperatures (Table B-I), the

TABLE B-I. POWER OUTPUT OF SURFACE DISCHARGES AT SIX GEOTHERMAL SITES, HONDURAS (modified by Goff et al., 1987a)

Area	Estimated Surface Discharge (ℓ/min)	Estimated Reservoir Temperature (°C)	Ambient Temperature (°C)	Thermal Energy (MW)	Electrical Energy Equivalent[a] (MW)
Platanares	3370	225	27	44.9	6.7
San Ignacio	1200	190	28	13.8	2.1
Azacualpa	3300	185	28	36.8	6.0
Pavana[b]	1000	150	30	8.4	---
La Ceiba Region					
Sambo Creek	2000	155	30	17.6	---
La Labor	1250	130	30	8.8	---
La Masica	500	130	30	3.5	---
El Olivar[c]	200	120	30	1.3	---

[a] Conversion of thermal energy to electrical energy is assumed to be roughly 15% efficient but practical only if reservoir exceeds 180°C.

[b] Other sites in Choluteca region not calculated because of low-temperature reservoir (≤100°C).

[c] Includes both El Olivar and Laguna Agua Caliente sites.

surface energy output of Platanares is 45 MW(thermal), whereas the surface output of San Ignacio is 14 MW(thermal) and Azacualpa is 37 MW(thermal) (Goff et al., 1986; 1987a; unpublished letter report; Truesdell et al., 1986).

Because Platanares was clearly identified as the best site in Honduras because of subsurface temperature (~225°C) and discharge rate (~3370 ℓ/min), subsequent investigations were conducted in January and February 1987. Thermal waters are Na-K HCO_3-SO_4-Cl in character with significant concentrations of As, B, F, Li, and NH_4 and low concentrations of Ca and Mg. Total dissolved solids are only 1100 mg/kg (Table B-II). Clear mixing trends can be seen in plots of B versus Cl, Li versus Cl, etc., between boiling waters, mixed waters, and near-surface waters (Fig. B-1). Gas chemistry of the boiling springs reveals they are relatively high in CO_2 with significant concentrations of H_2S, NH_3, and CH_4 (Table B-III). Stable isotope data reveal that recharge to the geothermal reservoir comes from local precipitation because surface waters and reservoir waters have similar deuterium contents (Fig. B-2). On the other hand, an oxygen-18 isotope shift of approximately 0.5 to 1.0°/₀₀ indicates rock water exchange at a temperature of ≥200°C. Very anomalous concentrations of B, SO_4, and NH_3 and a ^{13}C-CO_2 signature of ~11°/₀₀ indicate the geothermal reservoir is equilibrated in Cretaceous red beds of the Valle de Angeles Group.

A summary of the various chemical geothermometers is shown in Table B-IV. The quartz geothermometers are considered to be too low owing to quartz precipitation from the hot fluids. Quartz veins and silica sinter deposits occur throughout the main hot spring area. Good agreements exist between cation, $\delta^{18}O$-SO_4, and gas geothermometers, suggesting a reservoir temperature of 225°C, possibly as high as 240°C.

Abundant tritium samples were collected from end-member waters, mixed waters, and cold waters. These data were fit to a set of empirical curves based on two types of geothermal reservoir scenarios (piston flow and well mixed) to determine both the maximum age of fluids in the reservoir and the estimated reservoir volume (Goff et al., 1987; unpublished letter report). Based on this mathematical treatment of the data, end-member waters representative of the geothermal reservoir (average of 0.25 tritium units) have a mean residence time in the reservoir of approximately 900 years. The volume of the reservoir, V, can be estimated from the simple equation:

TABLE B-II. MAJOR CHEMISTRY[a] AND ISOTOPE DATA[b] FOR THE PLATANARES GEOTHERMAL SYSTEM

Sample[c] No.	Temp. (°C)	Field pH	SiO_2	Na	K	Li	Ca	Mg	Cl	F	HCO_3	CO_3	SO_4	B	As	NH_4	δD	$\delta^{18}O$	^3H	$\delta^{13}C$
End-Member Geothermal Water																				
PL-1	99.5	8.75	288	310	38	4.04	2.5	0.06	36.7	12.4	78.1	206	225	16.7	1.26	10.4	-41.6	-6.14	--	-8.72
PL-26	98.7	8.7	296	311	37	3.90	2.4	<0.1	35.9	13.3	18.3	247	242	17.0	1.1	3.30	-43.1	-5.93	--	--
PL-3	100.1	8.75	277	305	36	3.85	3.0	0.04	33.4	12.7	171	168	238	15.5	0.89	13.0	-42.4	-6.17	0.09	-7.69
PL-24	99.0	8.7	278	291	34	3.60	1.3	<0.1	34.4	13.1	64.7	209	236	16.8	0.8	4.20	-43.2	-6.20	0.34	-9.06
PL-5	96.0	8.3	305	289	18	3.56	1.2	0.06	36.0	12.3	154	142	239	16.0	0.88	11.9	-41.6	-6.03	0.12	--
PL-28	98.0	8.5	313	285	19	3.40	5.0	<0.1	34.9	13.1	91.5	187	235	18.1	0.9	4.23	-42.2	-5.94	0.76	-8.42
PL-7	98.5	8.75	236	311	26	3.53	3.8	0.08	34.4	12.6	171	154	245	16.0	0.79	9.5	-42.1	-6.12	--	-7.23
PL-36	98.3	8.7	251	305	29	3.50	2.2	<0.1	33.7	13.3	80.5	203	251	16.9	0.8	4.50	-44.9	-5.93	--	--
PL-8	98.6	8.75	233	299	37	3.72	1.0	0.04	34.0	12.9	68.3	202	246	16.4	0.68	7.95	-42.7	-6.00	0.41	-7.11
PL-17	98.2	8.9	242	304	40	3.80	1.1	<0.1	34.5	13.0	35.4	229	249	17.1	1.0	2.65	--	-5.96	1.07	-8.34
PL-2	99.3	8.75	290	291	33	3.50	3.2	0.07	35.4	12.9	215	132	215	16.4	1.00	11.7	-42.8	-6.03	--	--
PL-20	95.0	8.8	283	317	41	4.10	1.4	<0.1	34.8	13.0	199	188	240	17.0	1.0	3.30	-44.4	-6.26	0.46	-8.07
PL-22	98.4	9.1	292	333	37	4.00	1.3	<0.1	35.9	13.2	28	251	248	17.2	1.1	4.30	-46.5	-6.21	--	--
PL-23	95.0	8.0	233	305	35	3.70	8.9	0.3	33.5	12.4	276	139	231	16.1	1.0	8.08	-41.0	-6.44	0.90	--
PL-27	99.0	8.5	282	303	35	3.70	6.5	<0.1	34.4	13.3	32.9	238	240	19.4	0.9	3.61	-43.4	-6.02	--	--
Mixed Geothermal Water																				
PL-4	88.3	6.80	183	231	26	2.94	20.9	1.54	25.9	9.6	473	0	193	12.2	0.71	17.3	-44.0	-6.33	0.96	--
PL-6	92.0	7.20	183	260	21	3.29	5.4	0.08	26.0	9.5	530	0	199	12.5	0.58	11.0	-44.6	-6.02	--	--
PL-10	38.4	6.30	35	45	10.3	0.28	42.2	8.73	6.2	0.84	137	0	128	2.27	0.05	0.09	-42.1	-6.51	--	--
PL-11	70.8	7.40	191	230	25	2.86	16.3	1.19	31.2	12.4	355	0	232	15.0	0.21	17.1	-43.6	-6.09	--	-6.78
PL-12	35.1	6.60	39	52	20	0.45	42.7	11.7	7.2	0.85	187	0	135	2.76	0.39	0.15	-41.2	-6.53	5.14	--
PL-14	37.1	7.00	84	91	11.0	0.99	43.3	10.2	11.4	3.49	229	0	160	5.35	<0.05	0.09	--	--	--	--
PL-15	54.0	7.50	107	113	23	1.60	70.2	1.34	10.2	5.0	456	0	94	5.12	<0.05	9.7	-46.9	-6.94	2.37	--
PL-41	52.8	6.5	107	117	22	1.69	73.0	1.4	11.2	5.37	475	0	98	5.56	0.4	4.13	-47.4	-6.97	-	-9.57
PL-19	87.7	7.0	106	153	21	1.84	40.5	12.6	16.7	6.26	425	0	178	7.86	0.5	3.70	-49.0	-6.94	2.40	-9.14
PL-21	65.6	6.8	171	216	27	2.90	35.7	4.9	22.5	8.76	481	0	188	10.4	0.5	5.31	-45.8	-6.76	--	--
PL-25	68.6	6.7	208	255	29	2.70	16.4	2.9	30.6	11.9	503	0	224	14.6	0.6	9.76	-46.0	-6.62	0.59	--
PL-30	48.5	7.3	138	113	19	1.42	67.8	5.0	11.1	5.37	382	0	122	5.43	0.2	2.17	-47.4	-6.90	2.43	-6.81
PL-32	97.6	8.0	198	258	18	2.70	4.6	<0.1	32.6	12.8	284	64.8	214	16.9	0.6	8.11	-45.0	-6.44	0.53	--
PL-33	79.0	6.0	185	326	22	3.00	7.8	0.2	32.9	11.4	594	0	214	16.4	0.6	5.33	-46.2	-6.04	0.46	-7.47
PL-34	89.6	6.5	217	275	19	3.10	8.0	<0.1	32.5	12.5	488	0	212	16.4	0.5	8.55	-47.6	-6.60	--	--
PL-43	21.0	6.8	76	132	24	1.94	32.3	1.4	14.7	4.55	279	0	139	6.75	0.7	<0.02	-40.5	-5.35	--	--
Cold Water																				
PL-9	26.7	6.9	22	10	1.6	<0.01	72	15.5	2.6	0.21	45.7	0	110	0.03	<0.05	0.12	-42.8	-7.01	5.5	8.48
PL-18	23.4	7.6	17	8.9	16	<0.02	64.1	11.8	1.4	0.2	189	0	78.6	0.03	<0.1	0.03	-45.4	-7.29	--	--
PL-45	27.0	7.0	22	10.5	1.9	<0.1?	71.4	14.2	1.4	0.21	171	0	121	0.03	<0.1	0.06	--	--	8.3	--
PL-13	25.3	7.1	17	5.0	2.5	0.04	20.8	4.56	2.7	0.48	32.9	0	50	<0.02	<0.05	0.12	-39.5	-5.92	--	--
PL-29	24.2	6.0	19	9.8	2.4	0.02	19.0	3.5	1.1	0.56	32.9	0	40.4	0.03	<0.1	0.04	-43.0	-6.48	4.62	--
PL-16	28.0	7.0	31	17.0	3.3	0.06	49.9	10.2	3.3	0.27	183	0	48.4	0.11	<0.05	0.13	-37.7	-5.95	7.24	--
PL-42	20.7	7.2	28	9.4	2.3	<0.01	38.8	7.6	0.9	0.22	92.7	28.8	24.3	0.07	<0.1	<0.02	-42.4	-6.72	--	--
PL-31	21.5	6.0	48	6.2	3.9	<0.01	2.0	0.2	0.8	0.19	34.2	0	0.3	0.03	<0.1	0.03	-31.6	-4.37	2.55	--
PL-35	21.4	6.8	83	16.2	5.2	0.02	17.7	0.9	1.0	0.30	112	0	1.3	0.09	<0.1	0.06	-42.8	-6.13	2.02	--
PL-37	25.0	6.5	51	16.8	3.5	0.01	28.6	3.6	1.7	0.35	154	0	7.7	0.23	<0.1	0.03	--	--	--	--
PL-38	23.0	7.5	27	11.1	2.2	<0.01	41.3	7.1	1.8	0.28	123	28.8	24.3	0.06	<0.1	<0.02	-43.8	-6.29	--	--

[a]Chemical analyses reported in Mg/Kg.

[b]δD and $\delta^{18}O$ reported in ‰ relative to Standard Mean Ocean Water (SMOW); $\delta^{13}C$ reported in ‰ relative to Peedee Belemnite (PDB); tritium (^3H) reported in Tritium Units (T.U.).

[c]Sample numbers enclosed by brackets came from the same sampling location; sample numbers PL-1 to PL-16 from May 1985; sample numbers PL-17 to PL-45 from January-February 1986.

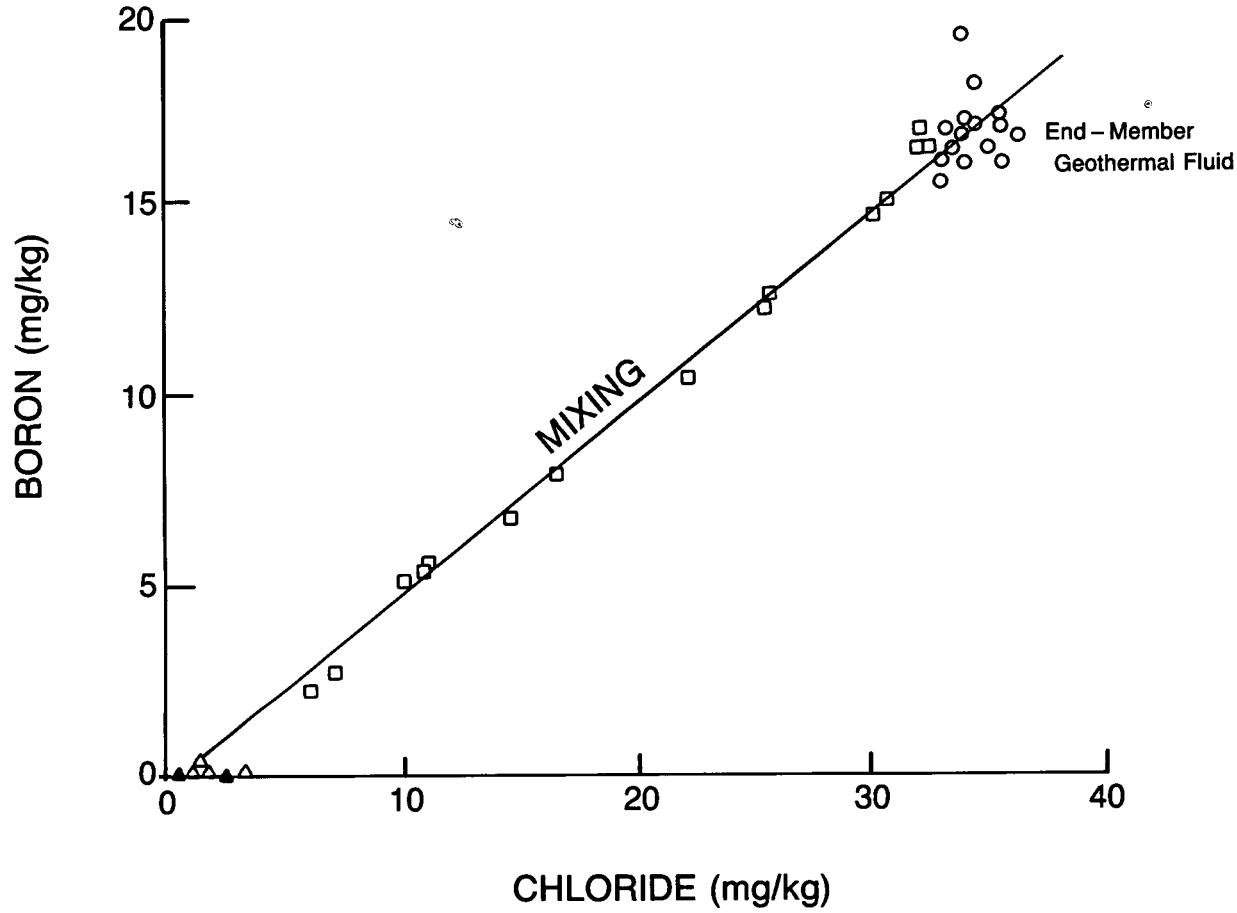


Figure B-1. B versus Cl, Platanares; triangles are cold waters, squares are mixed waters, and circles are end-member waters.

$$V = \dot{q}\ (\tau) \tag{1}$$

where $\dot{q}$ = steady-state discharge rate and τ = mean residence time of fluid. For Platanares (discharge rate of 3370 ℓ/min), the estimated reservoir volume is 1.6 km^3 of reservoir fluid. Assuming 10% porosity of reservoir rock, the volume of the geothermal reservoir would be 16 km^3.

Exploration coreholes PLTG-1, -2, and -3 were drilled from October 1986 to June 1987. Bottom-hole temperatures are 160°C at 650 m, 104°C at 401 m, and 165°C at 679 m, respectively. Coreholes PLTG-1 and -3 produce considerable amounts of geothermal fluid from depth and show isothermal temperature profiles for much of their depth (Fig. B-3). PLTG-2 shows an apparent conductive

TABLE B-III. GAS CHEMISTRY OF HOT SPRINGS OF HONDURAS[a]

Field No.	Site	Date	Measured Temp, °C	CO_2	H_2S	H_2	CH_4	N_2	NH_3	O_2	Ar	He	Total	^{13}C-CO_2
SAN IGNACIO REGION														
SI-2	San Ignacio	05/15/85	99.0	88.3	0.6075	0.2296	0.35025	5.55	4.846	0.01669	0.14685	0.000990	100.05	-11.75
SI-3	San Ignacio	05/15/85	98.9	91.3	1.768	0.1342	0.07293	4.987	1.681	0	0.1311	0	100.07	-11.01
SI-4	San Ignacio	01/25/86	99.6	77.58	6.082	0.5487	0.3387	9.815	5.156	0.06837	0.2496	0.004	99.84	-18.47
SI-7	San Ignacio	05/15/85	98.0	90.58	5.163	0.07295	0.06078	2.492	1.591	0	0.06698	0	100.03	-12.8
SI-9	San Ignacio	01/08/86	98.6	87.98	6.06	0.3625	0.3565	3.268	1.81	0	0.09996	0.0014	99.94	-13.3
SI-15	San Ignacio	01/25/86	98.2	93.75	2.126	0.1724	0.2073	2.428	1.215	0	0.07252	0.001	99.97	-9.51
PLATANARES REGION														
PL-1a	Platanares	05/17/85	99.5	81.62	2.587	0.03088	0.3175	0.9297	14.46	0.006261	0.02371	0.000050	99.98	-10.84
PL-1b	Platanares	05/17/85	99.5	82.02	3.006	0.03437	0.2164	1.167	13.54	0.00362	0.0276	0	100.01	-10.76
PL-3	Platanares	05/17/85	100.1	88.66	1.557	0.01654	0.3406	3.55	5.822	0	0.0901	0	100.04	-10.05
PL-17	Platanares	02/03/86	98.2	72.11	2.856	0.02395	0.5463	7.148	17	0.07775	0.1708	0	99.93	-12.17
PL-22	Platanares	02/04/86	98.4	90.97	0.17	0.03377	1.263	6.289	0.01027	1.019	0.1508	0.0011	99.91	-8.46
PL-23	Platanares	02/04/86	95	75.8	11.03	0.01028	0.1614	6.109	6.182	0.5662	0.1409	0	100.00	-12.78
PL-27	Platanares	02/04/86	98.5	85.55	2.13	0.02915	0.7624	3.4	7.948	0	0.08154	0.0006	99.90	-10.03
PL-28	Platanares	02/04/86	98.3	87.99	1.625	0.04174	0.1957	2.901	7.086	0.03004	0.06997	0	99.94	-9.79
PL-36	Platanares	02/04/86	98.3	82.06	1.944	0.01223	0.1237	4.875	10.67	0.1109	0.1147	0	99.91	-12.88
AZACUALPA REGION														
AZ-4	Azacualpa	05/24/86	100.3	76.66	5.453	0.03875	0.3173	15.59	1.084	0.4151	0.3692	0.002437	99.93	-12.63
AZ-4	Azacualpa	05/28/86	99.8	76.5	4.68	0.05859	0.3515	15.9	1.882	0.01712	0.3754	0.0045	99.77	-11.68
AZ-6	Azacualpa	05/24/85	101.4	79.87	0.224	0.07282	0.867	18.04	0.021	0.7417	0.5188	0.00835	100.36	-7.04
AZ-12	Azacualpa	01/28/86	99.5	83.14	1.445	0.02514	0.5278	13.56	0.5874	0.1807	0.37	0.0046	99.84	-9.66
AZ-23	Azacualpa	01/28/86	97.0	78.88	0.5273	0.07526	0.9284	18.46	0.01662	0.3836	0.5402	0.0092	99.82	-7.84
WEST OF AZACUALPA REGION														
AZI-24	Island NW Azacualpa	01/29/86	75.0	11.26	0.6868	0	1.54	83.0	0.0114	0.2955	1.41	0.0171	98.22	-16.16
EL CAJON REGION														
VI-2	El Cajon	01/31/86	50.0	4.33	0	0	0.426	91.33	0.007508	1.015	1.242	0	98.35	--
LA CEIBA REGION														
SC-3	Sambo Creek	05/21/85	99.5	12.58	4.809	0.02366	0.8064	76.97	0.3992	1.428	2.439	0.03714	99.49	-14.73
EL OLIVAR REGION														
EO-1	El Olivar	05/23/85	66.4	97.33	0.005822	0.0001	0.3124	1.695	0.01591	0.5903	0.02634	0.000064	99.98	-2.69
EO-7	Laguna Agua Cal.	05/23/85	67.8	99.39	0.03069	0.000590	0.1126	0.3923	0.007614	0.04948	0.00958	0.000277	99.99	-3.56
CHOLOTECA REGION														
PV-3	Pavana	05/29/87	101.8	71.81	3.542	0.0033	0.141	18.35	0.3991	4.987	0.5068	0	99.74	-9.74

[a]Gas concentrations are reported in volume percent.

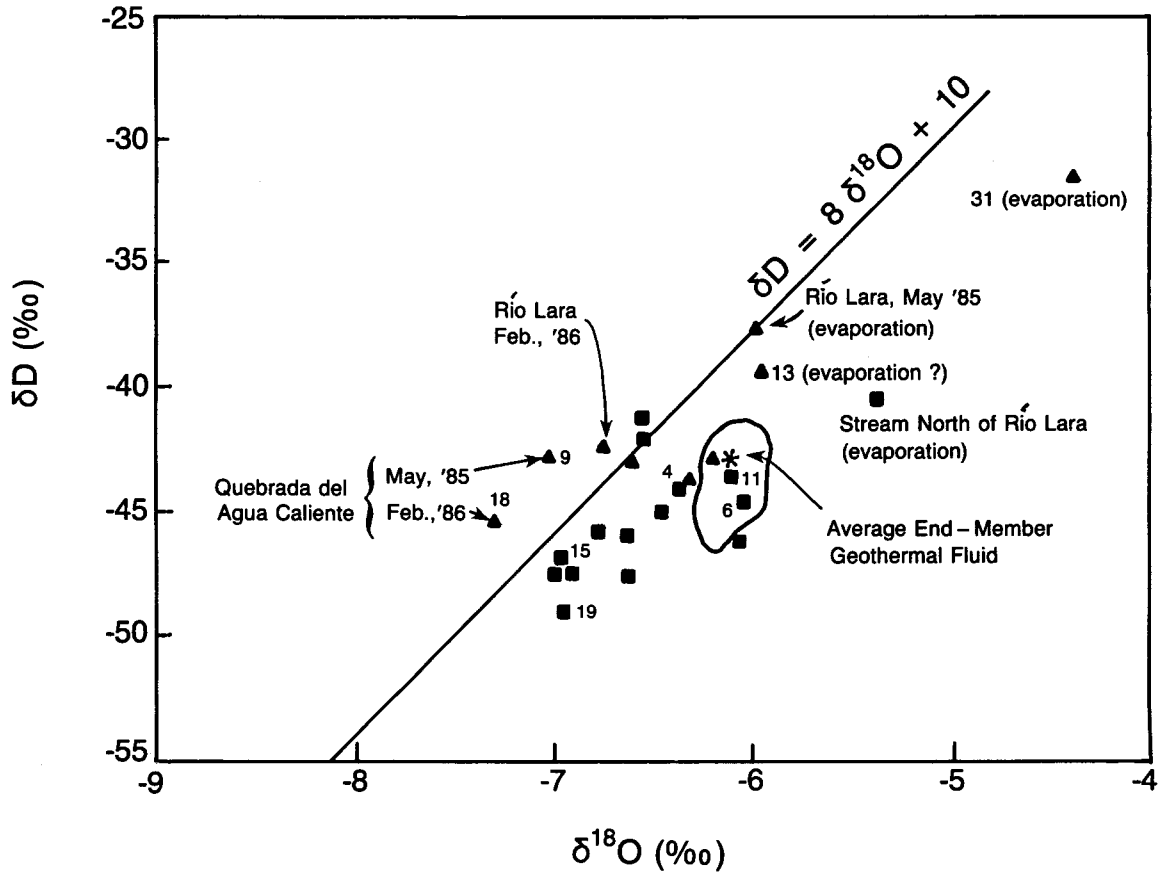


Figure B-2. Stable isotope data, Platanares; symbols same as Fig. B-1. Solid line outlines the cloud of points representing end-member geothermal fluids.

gradient of 139°C/km in the bottom one-third of the bore. Using thermal conductivity data acquired from the core, the heat flow in the lower zone of PLTG-2 is 265.7 mW/m^2 (6.4 HFU) implying that a convecting geothermal resource underlies the PLTG-2 site. Downward continuation of the 139°C/km gradient to the estimated reservoir temperature of 225°C implies that the depth to the source reservoir is 1.2 to 1.5 km.

Flow tests were carried out in both the PLTG-1 and PLTG-3 coreholes although transient analysis of PLTG-3 is yet incomplete. Chemistry of fluids from PLTG-1 and -3 resemble fluids in surface boiling hot springs (Truesdell et al., 1987). Although fluids are produced from fractured red beds at 160° to 165°C, geothermometers imply a source reservoir of 225°C (similar to the springs). Short flow tests of eight and six days for the two coreholes yielded

TABLE B-IV. CALCULATED GEOTHERMOMETERS FOR END-MEMBER GEOTHERMAL FLUIDS, PLATANARES, HONDURAS

Field No.	Measured Temp. (°C)	Qtz[a]	Na-K	Na-K-Ca β = 1/3	Na-Li	$\delta^{18}O$-SO_4 T_1[a]	$\delta^{18}O$-SO_4 T_2[b]	Gas T_{D-P}[c]	Gas $T_{CO_2-CH_4}$[d]
PL-1	99.5	206	235	225	300	248	220	230	181
PL-1(2)[e]	99.5	--	--	--	--	--	--	238	195
PL-2	99.3	207	228	216	289	--	--	--	--
PL-3	100.1	203	232	221	296	253	224	205	182
PL-5	96.0	211	179	190	292	--	--	--	--
PL-7	98.5	192	202	197	281	254	224	--	--
PL-8	98.6	191	236	235	293	261	229	--	--
PL-17	98.2	193	242	239	294	272	236	223	157
PL-20	95.0	205	240	236	299	261	228	--	--
PL-22	98.4	207	226	228	289	--	--	185	135
PL-23	95.0	191	229	207	290	--	--	228	203
PL-24	99.0	204	231	228	293	268	233	--	--
PL-26	98.7	208	232	224	295	--	--	--	--
PL-27	99.0	205	230	211	291	--	--	217	151
PL-28	98.0	213	185	180	288	267	232	234	201
PL-36	98.3	196	213	210	282	269	234	210	215
Ave.[f]	--	202±7	223±19	216±17	291±5	261±8	229±5	219±17	180±27

[a] No steam loss.

[b] Continuous steam loss.

[c] D'Amore and Panichi (1980).

[d] Norman and Bernhardt (1981).

[e] Collected for gas only.

[f] Error reported is standard deviation.

TABLE B-V. FLOW TEST DATA FROM PLTG-1 AND PLTG-3 COREHOLES, PLATANARES, HONDURAS

	PLTG-1	PLTG-3
Date	Feb. 1987	June 1987
Maximum Flow Rate	350 ℓ/m	515 ℓ/m
BHT	160°C	164°C?
Shut-In Pressure	110 psia	130 psia
Flowing Wellhead Temperature	138°C	150.5°C
Flowing Pressure @ Max. Flow	30 psia	70 psia
Maximum Temperature after Shut-In	145°C	158°C
Power Output @ Maximum Flow	~3.0 MW(t)	~4.4 MW(t)
Total Depth	650 m	679 m
Flow Zone	625-640 m	458 m; 622-635 m
Well Diameter	7.8 cm (3.0 in.)	7.8 cm (3.0 in.)

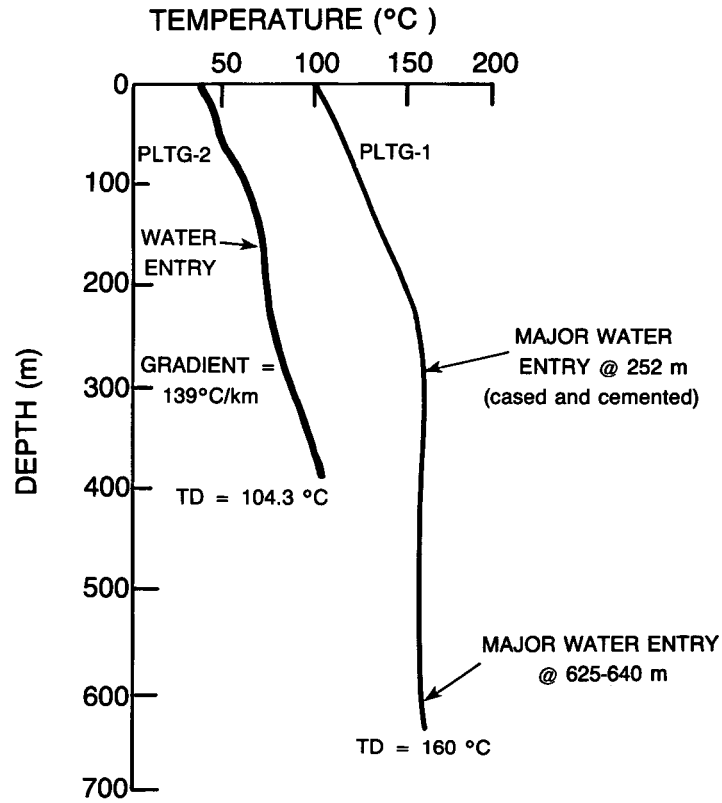


Figure B-3. Temperature-versus-depth profiles for PLTG-1 and -2.

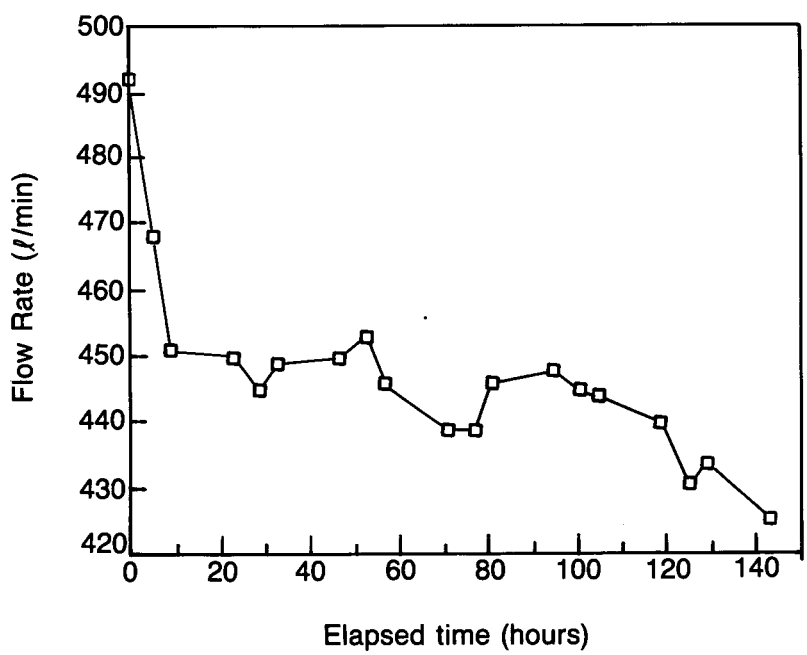


Figure B-4. Flow test versus time for PLTG-3 (six-day test).

steady-state flow rates of about 320 and 430 ℓ/min (uncorrected for flash) (Fig. B-4). A summary of data for the two wells is listed in Table B-V. The wells produce roughly 3.0 and 4.4 MW(thermal), respectively, which is very impressive for 3-in. coreholes. Permeability determinations on fractured core from PLTG-1 are about 300 md. Many fractures are over 1 m in length in the interval 625 to 640 m (Goff et al., 1987b).

Reservoir Model

Figure B-5 shows our model of the Platanares geothermal system schematically superimposed on the A-A' cross section of Heiken et al. (1986). From the high contents of NH_4, B, and SO_4 in the thermal fluids and the high concentrations of NH_3 and depleted $\delta^{13}C$-values of CO_2 in the gases, we strongly

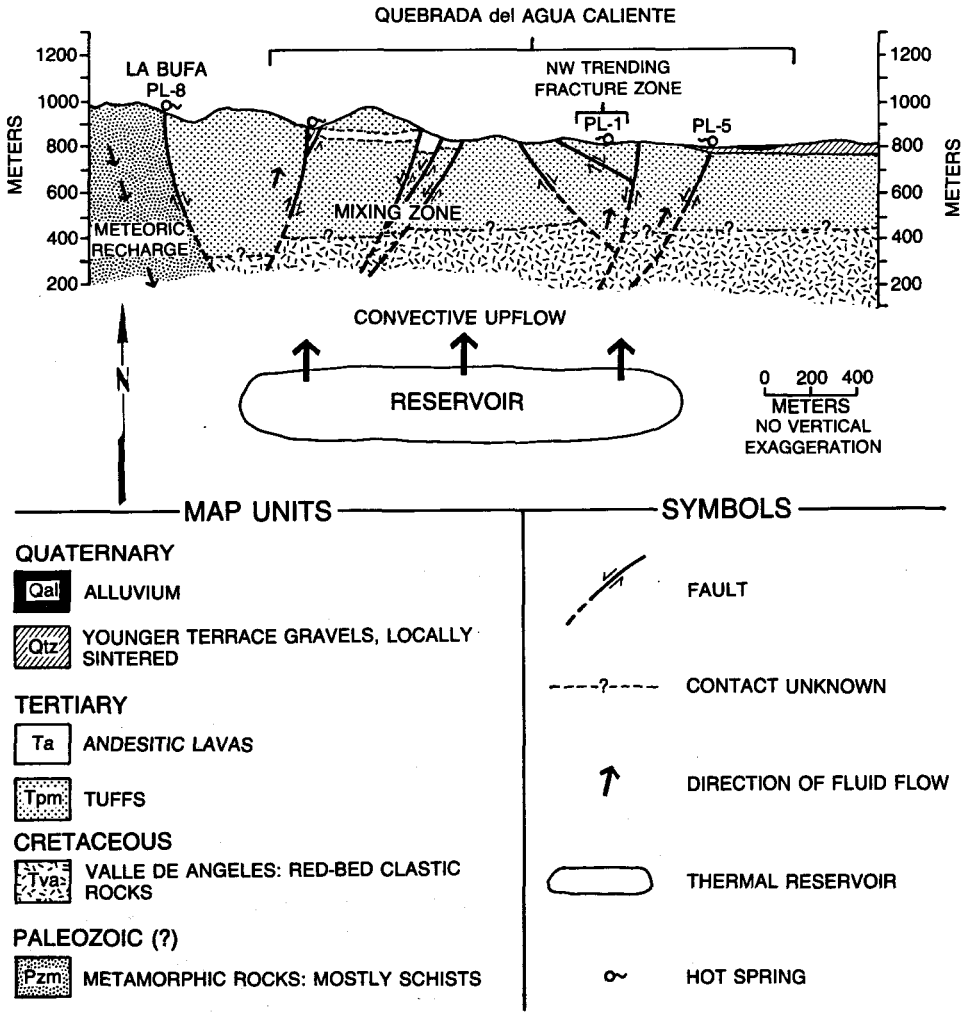


Figure B-5. Model of Platanares reservoir (from Goff et al., 1987a).

believe that the geothermal reservoir equilibrated in fractured red beds of the Valle de Angeles Group. This has been verified from drilling. This rock group is known to contain gypsum, petroleum, organic deposits, and marine clay shales in the upper half of the sequence (Finch, 1981), which could supply SO_4, NH_3, CO_2, H_2S, and B during thermal metamorphism.

Our work shows that the major hot springs discharge along a northwest-trending fracture system across the entire width of a structural graben (springs PL-8 to PL-5). Because hot end-member fluids also encompass this entire zone, it appears to us that the reservoir underlies the entire graben and not just one fault block. The northwestern limit of the reservoir is bounded by the major northeast-trending fault that juxtaposes Paleozoic schist (north) against Tertiary volcanics (south). Other limits of the reservoir are not well defined at this time, although mixed fluids discharge as far south as the Río Lara. Corehole PLTG-2 near the southern limit of hot springs has a conductive gradient of 139°C/km and a heat flow of 265 MW/m^2.

From constraints supplied by stable isotope data, recharge to the Platanares system probably comes from the higher elevations to the north and northwest. Tritium data suggest that the percolation rate is relatively slow and that the mean residence time of fluid in the reservoir is about 900 years. After heating and equilibration, geothermal fluid exemplified by end-member waters PL-1, PL-5, and PL-8 rises convectively along the many faults cutting the reservoir rocks. Reservoir fluid entering the fractured ignimbrite sequence of the Padre Miguel Group mixes with a deep, cool groundwater to produce mixed thermal waters. We feel that this deep groundwater must flow slowly through the Padre Miguel Group because geologic evidence indicates that these rocks extend to depths as great as 560 m and that the groundwater contains relatively high tritium (indicating a probable age of <u>not less</u> than 5 yr). We are uncertain as to the source of this cool groundwater because stable isotopes indicate that its average recharge elevation is roughly 150 m higher than that of the geothermal fluid in the reservoir, perhaps at the volcanic highlands to the northeast and south.

After thermal waters reach the surface, localized mixing occurs with shallow groundwater in alluvium along the Quebrada Agua Caliente and in colluvium along the canyon walls. The isotopes of this near-surface end member

resemble those of the quebrada as do their high tritium contents, which are above present background levels (indicating an age of only a few years).

Based on the cation geothermometry (Table B-IV), the average temperature of the geothermal reservoir appears to be at least 225°C. Temperatures based on quartz solubility are low because of precipitation of quartz or chalcedony during upflow. Temperatures based on D'Amore-Panichi gas geothermometry are in good agreement with the 225°C values. Temperatures based on SO_4-H_2O geothermometry agree if we assume continuous steam loss. According to drilling of PLTG-1 and PLTG-3, a shallow resource of 160° to 165°C occurs at depths of 250 to 680 m, but downward continuation of the temperature profile in PLTG-2 implies the deep 225°C resource occurs at a depth of 1.2 to 1.5 km.

REFERENCES

D'Amore, F., and Panichi, C., 1980, Evolution of deep temperatures of hydrothermal systems by a new gas geothermometer, Geochim. Cosmochim. Acta, v. 44, pp. 549-556.

Finch, R., 1981, Mesozoic stratigraphy of Central Honduras, Amer. Assoc. Petrol. Geol., v. 65(7), pp. 1320-1333.

Goff, F., Shevenell, L., Truesdell, A., Janik, C., Grigsby, C., and Paredes, J., 1986, Hydrogeochemistry and preliminary reservoir model of the Platanares Geothermal System, Honduras, Trans. Geotherm. Res. Counc., v. 10, pp. 125-130.

Goff, F., Truesdell, A., Grigsby, C., Janik, C., Shevenell, L., and others, 1987a, Hydrogeochemical investigations of six geothermal sites in Honduras, Central America, Los Alamos National Laboratory report LA-10785-MS, 170 pp.

Goff, F., Shevenell, L., Kelkar, S., Smith, D., Meert, J., and others, 1987b, Stratigraphy, temperature profiles, and flow test data from PLTG-1 and PLTG-2 coreholes, Platanares Geothermal System, Honduras, Trans. Geotherm. Res. Counc. (in press).

Goff, F., Truesdell, A., Shevenell, L., Janik, C., Grigsby, C., and others, unpublished, Hydrogeological report of the Second Honduras Sampling Trip, January-February 1986, Los Alamos National Laboratory letter report, 50 pp.

Heiken, G., Eppler, D., Wohletz, K., Flores, W., Ramos, N., and Ritchie, A., 1986, Geology of the Platanares geothermal site, Copán, Honduras, Los Alamos National Laboratory report LA-10634-MS.

Norman, D. I., and Bernhardt, C. A., 1981, Assessment of geothermal reservoirs by analysis of gases in thermal waters: Final Technical Report, New Mexico Energy Institute, New Mexico State University, Las Cruces, 130 pp.

Truesdell, A., Janik, C., Goff, F., Grigsby, C., Shevenell, L., and Paredes, J., 1986, The geochemistry of the San Ignacio Hot Springs, Honduras, Trans. Geotherm. Res. Counc., v. 10, pp. 155-160.

Truesdell, A., Stallard, M., Trujillo, P., Counce, D., and others, 1987, Interpretation of fluid chemistry from the PLTG-1 exploratory drill hole, Platanares, Honduras, Trans. Geotherm. Res. Counc. (in press).

APPENDIX C

SUMMARY OF THE GEOPHYSICS OF THE PLATANARES GEOTHERMAL AREA, COPAN, HONDURAS

Michael Gerety
Los Alamos National Laboratory

INTRODUCTION

Los Alamos National Laboratory, in cooperation with Empresa Nacional de Energía Eléctrica de Honduras and the U.S. Geological Survey, performed a geological-geochemical-geophysical reconnaissance of potential geothermal sites in Honduras as part of the Central American Energy Resources Project.

The geophysical reconnaissance program consisted of two parts: 1) a regional, country-wide investigation designed to identify (if possible) distinct geothermal provinces within Honduras; 2) local studies designed to help evaluate the geothermal potential of two known geothermal areas (Platanares and San Ignacio). The regional results will not be discussed in this report.

The local studies at Platanares and San Ignacio used the same approach. However, only the results from the Platanares work will be discussed in this report. Figure C-1 is part of the topographic base map used at Platanares. At each of the two areas the following work was done:

1. A detailed gravity survey was integrated with available regional gravity and geologic data to help identify major geophysical structures. Figure C-2 shows the results of this work.
2. Regional aeromagnetics were interpreted in an attempt to identify the major geophysical structures (fault zones and major rock units) in the regions surrounding Platanares and San Ignacio. The aeromagnetic data did not provide any local information and no map is presented here.
3. A detailed self-potential survey to search for streaming potential associated with the movement of geothermal fluid was performed at the two sites. Figure C-3 shows the data distribution and the location of interpreted self-potential anomalies.

GRAVITY WORK AT PLATANARES

A detailed gravity survey with about 500 stations was carried out in the Platanares area to identify the major density structures of the area and to relate this geophysical structure to the geologic structure. At Platanares the gravity data were the most helpful in identifying structures possibly related to the geothermal reservoir and the migration of fluids.

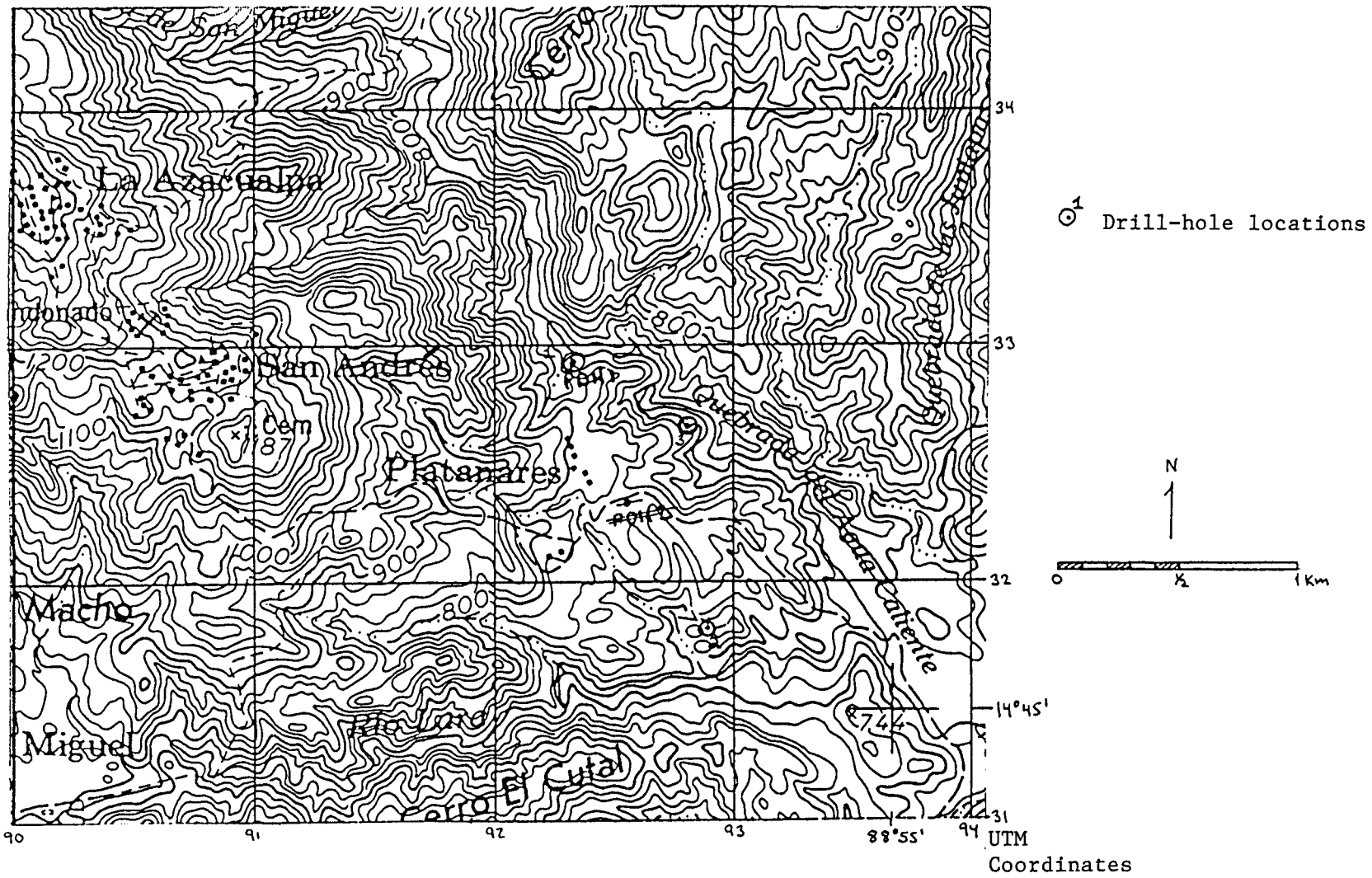


Figure C-1. Topographic base map for Platanares.

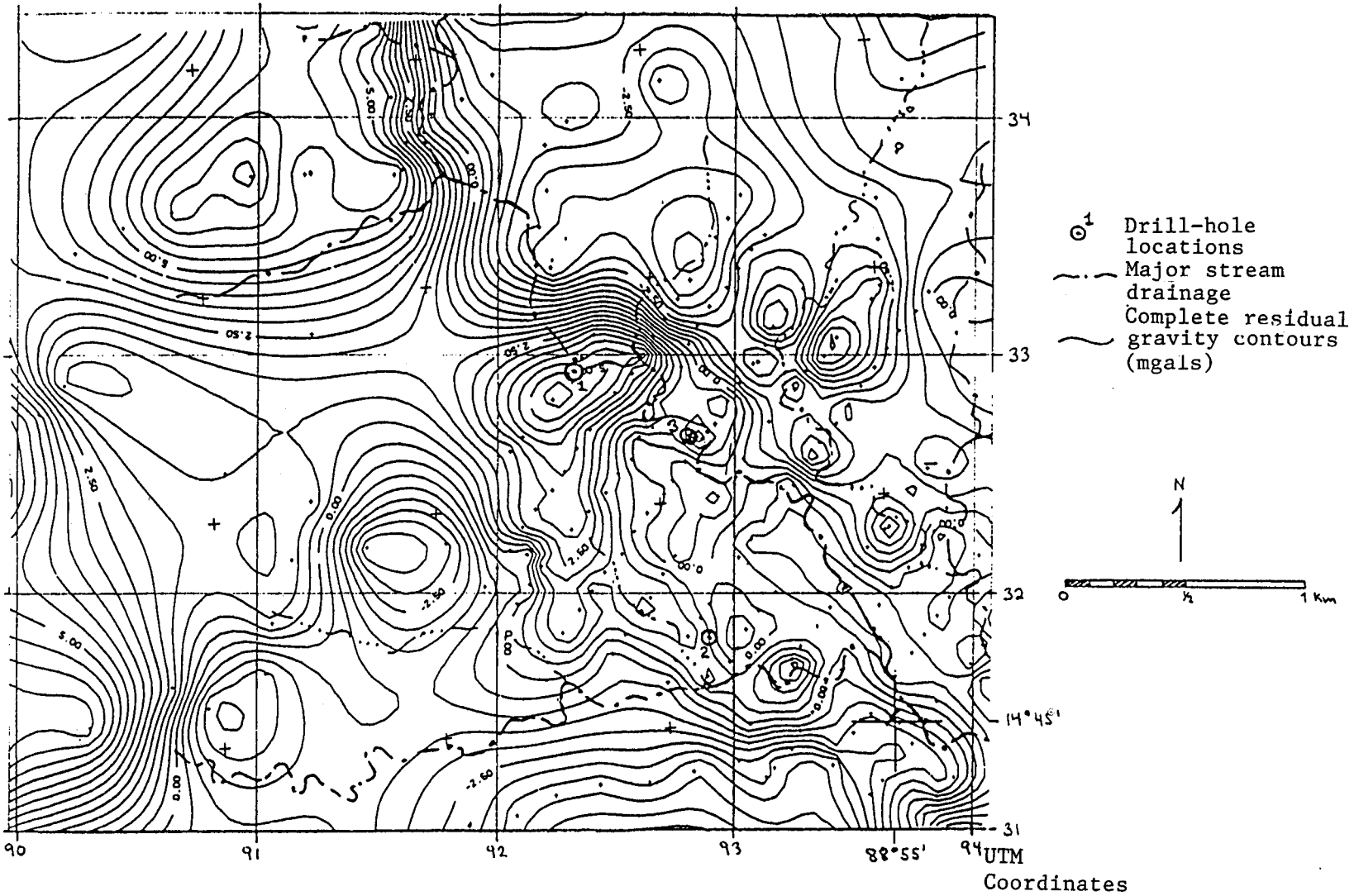


Figure C-2. Complete residual Bouguer gravity map for Platanares.

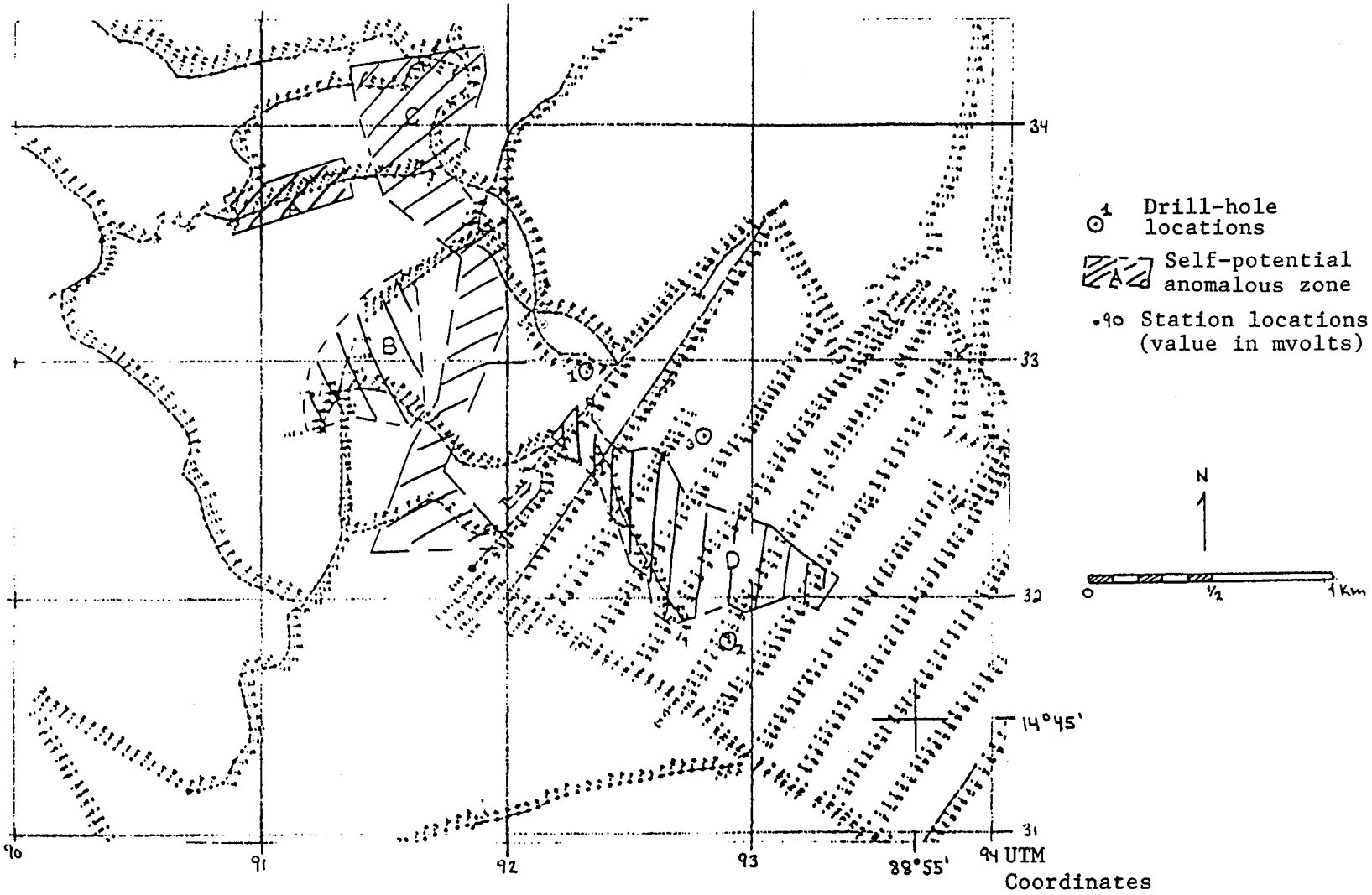


Figure C-3. Self-potential station location and anomaly map.

Stations were surveyed with a combination of electronic distance meter/ theodolite ("total station") and theodolite surveying. Each detailed survey site required that a long regional line be surveyed through it so that field locations within the detailed site area could be tied to known established benchmark locations found elsewhere. These established benchmarks are located at Cucuyagua for the Platanares survey. The survey data were processed so that absolute horizontal and vertical locations were obtained. The tie from Cucuyagua to Platanares had a 3-m elevation difference with a spot elevation located at San Andrés and negligible difference for other spot elevations in between. The difference is divided among the survey stations back to Cucuyagua so that the total error is approximately 0.02 m vertically. For any individual station the total error is about 0.1 m.

Terrain corrections of the gravity data were carried out by digitizing all the contours on the 1:20,000 base map and also digitizing, at a larger scale, maps out to 20 km from the survey area. A computer program was used to correct for the outer 0.05- to 20-km radius from each station using the digital terrain data. The innermost terrain effects were estimated in the field and corrected by hand. Complete Bouguer gravity maps were developed at different densities, from 1.8 through 2.8 g/cc. The results were examined to determine if any spurious terrain-related anomalies were produced by incorrect densities. A density of 2.50 g/cc for the Bouguer correction was determined as appropriate for the entire area.

The Complete Bouguer Gravity Map (Fig. C-2) shows three large mass excesses with a saddle connecting the two located in the northwest quadrant with the mass excess in the southeast quadrant. A smaller mass excess is located on the saddle. There is one major mass deficit in the southwest quadrant.

SELF-POTENTIAL WORK AT PLATANARES

The self-potential (SP) electrical technique was chosen for use at Platanares to locate zones of high vertical fluid movement that often occur in geothermal environments. The SP technique cannot be used quantitatively to determine the quantity of fluid flow, but it is often helpful in determining the location and geometry of flowing groundwater. Because the SP technique is useful for detecting vertical fluid flow and is easily performed in the field,

it is often used for geothermal exploration. A variety of mechanisms can cause SP effects, so the SP technique should always be followed by additional geophysical methods such as DC resistivity, gravity, and magnetics, as well as integrated with the known geology to help determine the appropriate source mechanism for specific anomalies.

Three sources of noise in the Platanares area make interpretation difficult: high contact resistance, local variation in soil properties, and temporal variation of hydrologic parameters. The noise levels in these data are sufficiently high so that only responses consistent from line-to-line and point-to-point were considered for interpretation. The data quality for this survey should be considered marginal. In considering the following anomalies, care has been taken to consider the reliability of the data. Figure C-3 shows the data coverage and anomalous zones for the Platanares area. The data values cannot be read at this scale, but the stations' locations illustrate the data coverage.

A. This anomaly consists of low voltage readings in the vicinity of reference point HE. The entire line HG-HF should be ignored owing to exceptionally high contact resistances (>1 Megohm). This feature probably has no geologic significance.

B. Low voltages exist in the vicinity of reference point DS. This feature is detected on several lines using different base stations and contains stations whose contact resistances are within acceptable values. This feature does result from geologic or hydrologic phenomenon.

The hydrologic interpretation of anomaly B is that it represents an area of outward migration of fluid such as water running downhill or flowing from one aquifer into a lower one through a fracture zone. Another explanation is that sulfide mineralization or graphite are present. The amplitude of the feature suggests the presence of sulfide material or fluid movement. It is too strong to represent a change in soil chemistry. A small amount of sulfide or a large quantity of water would be required to produce this anomaly. Mineralization is a likely source mechanism for this feature. A fluid source is considered unlikely owing to the amplitude of the anomaly.

C. This feature consists of high voltage values extending from reference points HN to AA. It comprises many points whose contact resistances are much too high to be considered reliable. If one were to ignore these bad data, the following conclusions could be reached:

- The hydrologic interpretation of this response is upward migration of fluid along a fracture zone.
- Mineralization would not cause a positive anomaly.
- The magnitude of the response is too high for soil variation.
- Fluid migration is considered the most likely source mechanism for this response.

Anomaly C parallels the fault zone containing all the hot spring occurrence (Quebrada del Agua Caliente). The feature is displaced to the west of the river and might indicate that the main upwelling of fluid is on the west side of the valley. This interpretation is, however, compromised by the percentage of questionable data contained within the zone.

D. This feature is 30 to 50 mV more positive than in the surrounding area. The data are noisy and contain points with unacceptably high contact resistances. Taking this into consideration, there is still enough consistent data to suggest that the anomaly has geologic and/or hydrologic significance. Any of the source mechanisms that produce SP responses could be responsible for the anomaly. These data are consistent with upward migration of geothermal fluid. This feature also parallels the Quebrada del Agua Caliente and is a possible extension of Anomaly C.

The overall data quality for this survey is poor. The primary reasons are the exceptionally high contact resistance and variability in soil properties. Care was taken to evaluate the reliability of particular anomalies, but even so the interpretations should be used cautiously. It is not recommended that any additional work be done to evaluate or interpret these data. These interpretations should be reconsidered as other geologic and geophysical data become available.

GEOPHYSICAL INTERPRETATION

The purpose of this section is to integrate all the geophysical data available at the Platanares site into a single cohesive interpretation. The data sets utilized for this are gravity (400 points), SP (1500 points), two magnetic flight lines, and a preliminary one-dimensional Schlumberger survey by Giorgio Stangalino (DAL, Milan, Italy).

The gravity data are the most useful in the Platanares area. Though the SP data set is more extensive, it was much less definitive. Hot spring locations and the electrical models support the overall interpretation. Figure C-4 (from Goff et al., 1987) shows the locations of the major faults and hot springs. Figure C-5 locates the electrical soundings and the drill-holes, both existing and proposed.

SUMMARY OF MAIN OBSERVATIONS

1. The main northwest-trending fault/fracture zone (graben) has a strong gravity signature. North of UTM coordinate 33, its western edge is defined by a prominent gradient. South of UTM 33 the graben is characterized by a northwest-trending mass excess (intrusive?). This mass excess resides entirely within the confines of the fault/fracture zone as mapped geologically.
2. All the major hot or warm springs are located on the northeast side of the mass excess. The highest thermal output in the area as measured from the hot springs occurs adjacent to the largest gravity anomaly. The Río del Agua Caliente follows along the gravity ridge the entire distance.
3. The geometry of the "intrusive" suggests that it has been broken by faulting. This episode of deformation may also have increased the transmisivity of the intrusive and its margins.
4. The only group of warm springs and chemical anomalies not in the Quebrada del Agua Caliente occur on the Río Lara and off the southern edge of the main gravity "intrusive."
5. Drilling at PLTG-1 encountered andesites, which could be the cause of the mass excess (intrusive). If so, the emplacement of the intrusive may have

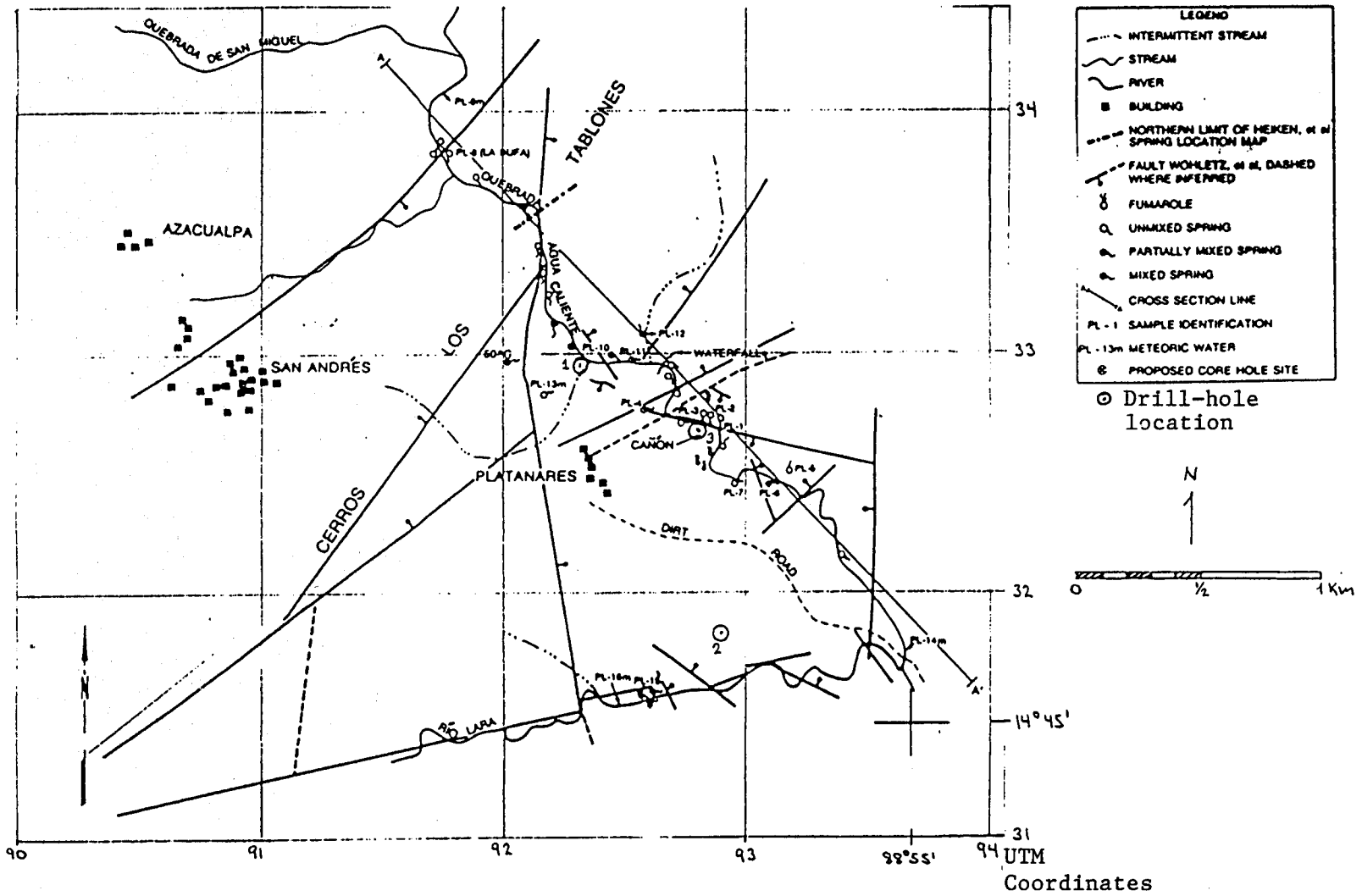


Figure C-4. Hot spring location map for Platanares. Taken from Goff et al., 1987.

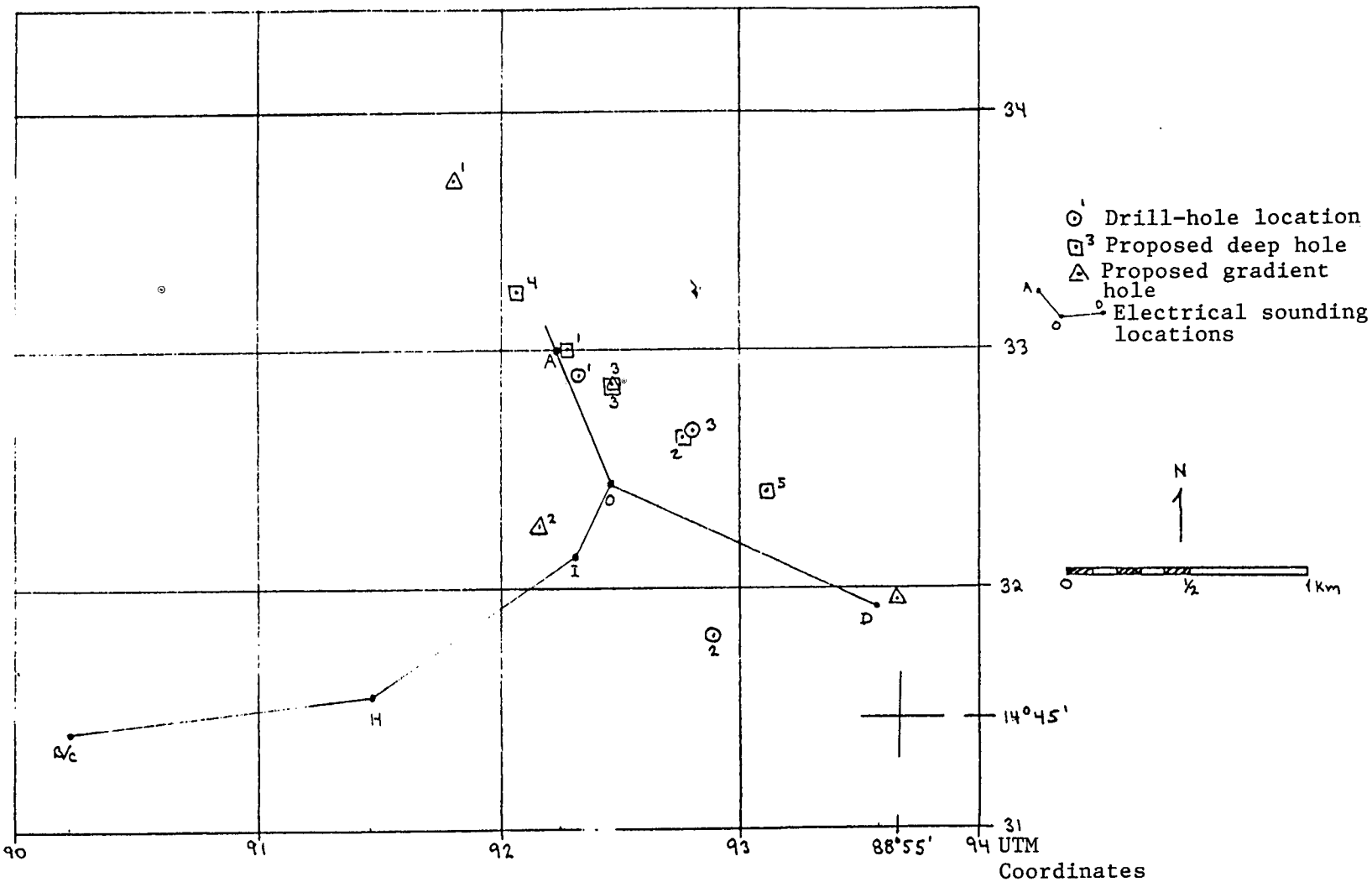


Figure C-5. Drill-hole and Schlumberger sounding location map.

increased the fracture permeability in the surrounding rock and enhanced the total permeability of the system.

6. Self-potential Anomaly D has its strongest response immediately adjacent to the gravity gradient of the suggested intrusive body. This response may or may not have geohydrologic significance.
7. Three Schlumberger models indicate 700-800 m of conductive (<20 ohm-m) material underlain by an undetermined thickness of >40 ohm-m material. These models are all from soundings on top of the gravity "saddle" structure.
8. The electrical sounding in the immediate vicinity of PLTG-1, i.e., in the immediate vicinity of the major mass excess within the fracture/fault zone, indicates the ground to be more resistive than in the other profiles.
9. The three electrical soundings done along the northwest-trending fracture zone show a more extensive zone of conductive ground than do other soundings.
10. Electrical soundings show no correlation with lithology as measured in any of the three drill holes PLTG-1, -2, or -3.
11. Magnetic data did not help to identify possible lithologies responsible for the gravity features. Only two lines come close to the area of interest, and neither comes close enough to correlate with the gravity data.

CONCLUSIONS

The primary control on the hot spring activity seems to be the northwest-trending gradient parallel to the Quebrada del Agua Caliente. Most of the hot spring activity is located on the northern side of the gravity saddle structure and follows along the steep gravity gradients to the northwest.

The second most important control on the shallow reservoir seems to be the more indurated or dense rock comprising the mass excess within the fracture zone. The highest thermal output measured in the Platanares area is on the steepest portion of the northwest gravity gradient just north of PLTG-3 where it intersects the major east-west-trending fault. This fault is seen in the geology and is apparent on the gravity map. The only other manifestations of warm springs or chemical anomalies occur on the Río Lara immediately adjacent to the southwest side of the same gravity gradient.

This mass excess appears from its morphology to be a zone of andesite dikes. There appear to be several faults offsetting parts of this dike swarm. One fault exists between PLTG-1 and PLTG-3, with PLTG-3 down-dropped from PLTG-1.

The mass excess is possibly an andesite intrusion or plug piercing the Valle de Angeles formation, thereby creating the conduits necessary for the geothermal system. Once the hot water reaches the major superficial fractures that control the location of the Río del Agua Caliente, it will manifest wherever it is most convenient.

The overall permeability of the mass excess may be less than the surrounding volcanic tuffs. Otherwise a mass deficiency would result. The only Schlumberger sounding in the vicinity of the mass excess shows more resistive rock, which does not appear to relate to lithology. This information supports the hypothesis presented. Unfortunately many other factors may influence the electrical results. The higher resistivities may be a result of the metamorphic unit outcropping to the northwest of the sounding.

If this hypothesis is correct, then the major upwelling of geothermal fluid is around the sides or up through the plug and then into the near-surface aquifers. If this is the case, then the most likely place for a reservoir is within the fractures immediately surrounding the "plug." The center of the anomaly is UTM 328923. This implies that any reservoir in the upper kilometer will result from fracture permeability, thereby implying denser, well indurated but broken rock units.

APPENDIX D

SUMMARY OF THE GEOTHERMAL GRADIENT DRILLING OPERATIONS, PLATANARES GEOTHERMAL AREA, COPAN, HONDURAS

Sue Goff

Los Alamos National Laboratory

During the spring and summer of 1986, planning and contract negotiations began for the initial geothermal gradient drilling at Platanares. Funds were available at the time for two ~500-m-deep coreholes. Swissboring Overseas Ltd. Guatemala was selected as the drilling contractor. The plan was to core as deeply as possible (at least 500 m) vertically with the hope of coring through the Padre Miguel Group into the Valle de Angeles Group, the suspected reservoir rocks.

The objectives of the effort were the following:

(1) obtain quantitative information on the temperature distribution as a function of depth;

(2) recover fluids associated with the geothermal reservoir;

(3) recover 75% or better core from the subsurface rock units; and

(4) drill into the subsurface rock as deeply as possible to obtain information on potential reservoir rocks, fracture density, permeabilities, and alteration histories of the rock units beneath the site.

The core rig, a Longyear 44 powered by a 4-71 GM diesel engine with a 20-ft mast, was mobilized by Swissboring. Mobilization efforts required acquisition of permits to cross borders, road improvements, site preparation, and construction of camping and mess facilities, office space, a field repair shop, and equipment and core storage areas.

PLTG-1 is located along a main northwest-trending fault and fracture system from which 95% of the thermal springs at Platanares issue. It was intended to penetrate hot water at shallow depths. This first continuously cored geothermal gradient hole in Honduras was spudded on October 19, 1986. A major eruption of hot water occurred at a depth of 252 m, wedging the core barrel with the HQ rods. Operations resumed with a closed circuit system, using loading chambers and continuous cooling with fresh water during nondrilling periods. Hot water entries occurred at various depths during the drilling, but tight control on the system prevented additional eruptions. The red beds of the Valle de Angeles were encountered at 563 m. Operations were shut down during December at a depth of 588 m. In mid-January a cementing job sealed off the major fluid entry of 150°C water at 252 m that was dominating the temperature of the borehole and preventing the determination of a conductive gradient. Drilling resumed with NQ rods to obtain an additional 50 m of hole

into the Valle de Angeles. On reaching 625 m another major eruption occurred, which was immediately controlled by switching to the closed circuit system with cooling as described above. The borehole was completed to a total depth of 650.4 m on January 21, 1987. PLTG-1 is producing water from the 625-640-m zone, and temperatures at the bottom of the borehole are dominated by this large water entry.

PLTG-2 is located 1 km south-southeast from PLTG-1 in a relatively unfaulted block away from the main hot spring area. The objective of PLTG-2 was to assess subsurface lateral flow of geothermal fluid away from the main hot spring area and to obtain a conductive temperature gradient that was not influenced by convective upflow in the main spring area.

The core rig was relocated to the PLTG-2 site on January 21, 1987, and the second borehole was spudded on January 22. Coring continued rapidly to 397.7 m, penetrating a red bed unit at 311 m. At a depth of 428 m the core barrel threads stripped and parted. The wireline broke near the surface, and the overshot assembly sent down the hole to retrieve the inner barrel was lost as well as the core barrel. Attempts to "kick around" the lost core barrel failed, and the hole was completed to 401 m on February 16.

PLTG-2 produces small quantities of water (5-10 ℓ/min) from the annulus of the HQ rods left in the borehole as a liner. The maximum temperature of PLTG-2 is 104.5°C at 401 m. The log shows two zones of high gradients: an upper zone where the gradient is ~239°C/km and a lower zone where the gradient is ~139°C/km. Estimated depth to the source reservoir of the Plantares system is ~1.2-1.5 km based on downward continuation of the lower gradient in PLTG-2.

The information obtained from the first two coreholes provided the impetus for a joint venture between Los Alamos, ENEE, and USAID Honduras to drill a third corehole. PLTG-3 was located to confirm the high temperature and permeability within the central region of the geothermal discharge zone observed in the first borehole.

PLTG-3 was spudded on May 9. A hot water eruption occurred on reaching a depth of 25 m, propelling the inner tube to the height of the eruption column at the top of the mast. After the eruption was controlled, the drilling continued. A red bed unit was encountered at a depth of 289 m and at 362.4 m, a fault zone was drilled and andesite was encounterd. The decision was made to step down to NQ core at 387 m in shaley zones. The Valle de Angeles was

encountered at 622 m and another major hot water entry at 625 m. The highly abrasive conditions in the Valle de Angeles created problems with bit life. Total depth of 679 m was reached on June 10.

The three slim exploration coreholes, drilled to depths of 650, 428, and 679 m, respectively, are the first continuously cored geothermal gradient holes in Honduras. Despite eruptions of hot water that occurred during the drilling of both the first and third boreholes and generally difficult drilling conditions, recovery of >98% core has been obtained.

APPENDIX E

RECOMMENDATIONS LETTER FROM CONSULTANT

Dr. Harry J. Olson
Hawaiian Electric Industries

University of Hawaii at Manoa

Hawaii Natural Energy Institute
Holmes Hall 246 • 2540 Dole Street • Honolulu, Hawaii 96822

3 September 1987

Dr. A. William Laughlin
P.O. Box 1663 MS-D 446
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Dear Bill:

Re: Recommendations for Continued Exploration and Development at the Platanares Geothermal Prospect, Honduras

First I would like to comment on the quality of the Platanares Geothermal Prospect, which I believe has a great potential for the discovery and development of both a shallow (<300 m, >150°C) and a deep (<2,000 m, >200°C) liquid-dominated geothermal reservoir. The areal extent of the prospect is such that a shallow reservoir capable of producing 5 to 10 megawatts of electricity for 30 years is a real possibility. Sufficient data also exist to strongly indicate the existance of a deep reservoir. However, if a deep reservoir is discovered and developed, the possibility that production from the deep reservoir may impair or prevent production from the shallow reservoir should be considered in any development planning. This eventuality should not be considered a developmental failure, as electrical power would be available prior to the time the deep reservoir would be developed and could supply power for the development of the deep resource. Also, if production from the deep reservoir were to dry up the shallow reservoir, the modular generating units could be used to develop and test other geothermal reservoirs in Honduras or neighboring countries.

Regarding the continued exploration and development of the Platanares prospect, before any further work is done the existing three coreholes should be logged to obtain equilibrated temperatures and geothermal gradients. Also, the planned AMT and other geophysical surveys should be completed to provide a better understanding of subsurface conditions at the prospect, and perhaps in conjunction with existing data to better define further drilling targets.

Sufficient technical data are available to indicate that viable resources may be present in both shallow and deep reservoirs and serve as the basis for

plans to continue testing and development of the prospect. At least three options for the development of the prospect exist. The option chosen will depend upon the requirements of ENEE, the type and size of reservoir needed, the amount of funding available, timing, and the level of risk that ENEE is prepared to accept.

Option I Develop the Deep Reservoir

1. Drill a maximum of three Temperature Observation Wells (TOW) to depths of at least 600 meters. The TOWs should be located and spaced so as to test as much of the prospect area as possible with the objective of defining a drilling target for a Test For Discovery (TFD) well to test the deep reservoir. The wells should be drilled as economically as possible using either diamond core or rotary drill rigs and should not be designed as production wells. Information received from these wells should include geology, hydrology, subsurface temperatures, and drilling conditions. Water samples should be collected if possible and analyzed. Composite core or rock chip samples should be collected and analyzed for gold, silver, mercury, arsenic, base metals, etc., if the rock samples appear to be mineralized. If the TOW is drilled by a rotary rig, chip samples should be mounted on chip boards for visual analysis and comparison with other rock and chip samples. If possible, downhole resistivity, self-potential, and gamma-ray geophysical logs should be taken. Temperature logs should be taken about a day after the well is completed. If practical, another temperature log should be taken a week or two after well completion. A final "equilibrated" temperature log can be taken approximately a month after well completion.

1A. If a management decision is made to assume the risk of not drilling TOWs, this step can be omitted. However, if the TFD well is unsuccessful, then one or more TOWs should be drilled to better define a production drilling target.

2. Drill a TFD well. This well should be designed as a production well with a total depth of approximately 2,300 meters and should be planned to intersect the deep reservoir at a depth of approximately 2,000 meters. The well should be stopped above a depth of 2,000 meters if the deep ($>200^{o}C$) reservoir is intersected. Prior to flow testing, the well should be logged with an applicable suite of logs, and if the completed well is to be cased, a cement bond log should be run immediately after the cement has set. An equilibrated temperature log should be taken prior to flow testing if possible, and well temperatures should be monitored after flowing until equilibrium is achieved.

2A. If the TFD well is successful a Comfirmation Production Well (CW) should be drilled. Design and depth of the well will be determined by the results of

the TFD well but should be similar to the initial well. The first well should be instrumented during the flow test of the CW to establish if communication between the two wells exists.

2B. If the TFD well is unsuccessful, and TOWs have not been drilled, one or more TOWs should be drilled to better define a drilling target for the deep reservoir.

Option II Develop the Shallow Reservoir

1. With a truck-mounted rotary rig, drill production wells to develop the shallow (<300m, >150°C) reservoir. A nominal seven-hole program would allow for six wells capable of producing one megawatt each and a "dry" hole which may be later utilized as an injection well. This would provide sufficient wells to support a five-megawatt binary-cycle geothermal plant with one standby production well. Additional injection wells would be required. The ultimate number of wells will be determined by drilling and flow test results. Electrical generation capability can be increased by adding binary generation modules until the reservoir capacity is reached. Well depth should be planned for 300 meters, but the drilling should be stopped and the wells completed if the reservoir is intersected at shallower depths. These wells should be logged and flow tested as outlined in Option I.

Option III Simultaneous Development of Both Reservoirs

1. Begin the development of the shallow reservoir as outlined in Option II.

2. Utilizing data developed from existing shallow production wells, site a TFD well to develop the deep reservoir as outlined in Option I. Sufficient data should be available from the production wells so that TOWs will not be needed.

I enjoyed the opportunity to review the data for this excellent prospect and would be pleased to assist in any way possible in the future.

Sincerely,

Harry J. Olson

Harry J. Olson
Hawaiian Electric Industries
Fellow in Geothermal Energy Research
University of Hawaii at Manoa

HJO:ek

APPENDIX F

PRELIMINARY RESULTS OF ECONOMIC ANALYSIS OF GEOTHERMAL ENERGY DEVELOPMENT

Linda Trocki
Los Alamos National Laboratory

SUMMARY

This discussion addresses the costs and benefits of installing a 10-MWe geothermal plant at Platanares as early as 1991. It is based on preliminary results from a dynamic optimization program. Future work, expected to be completed within one to two months, will result in an optimal expansion plan for ENEE.

Preliminary results indicate that the reduction in costs over a 20-year study period that are afforded by the installation of a 10-MW plant as early as 1991 amount to $21,500K (thousands of 1987 dollars). In addition, the revenues from electricity sales from the 10-MW plant could amount to approximately $46,000K in the plant operates as expected at an 80% capacity factor over the period 1991 through the end of the 20-year study period in 2008. The costs of the 10-MW plant are approximately $17,900K in initial capital expenditures plus operation and maintenance costs amounting to a sum of $2,300K in present value terms over the 18 years of the study period. Benefits of $21,500K in cost reduction plus $46,000K in value of output outweigh total present value of costs of $20,200K by a factor of more than 3 to 1. Based on this preliminary analysis, development of a 10-MW plant at Platanares by 1991 is warranted from an economic point of view.

I. INTRODUCTION

The economic feasibility of electricity generation from geothermal resources at Platanares is being analyzed with a computer code that determines a least-cost expansion plan for ENEE. The computer code, WASP, was recommended by the Inter-American Development Bank (IDB), is in use in several developing countries, and handles the probabilistic operation of hydroelectric projects explicitly--an important characteristic for a hydrodominated system such as ENEE's.

The following input data are required to simulate electricity system operation: expected increases in peak demand; present generating equipment, its expected life and the cost of its operation; hydrologic conditions and expected energy output of all hydroelectric plants under the possible

conditions, e.g., dry years, wet years, and normal years; and the cost and operating data about the thermal, geothermal, and hydroelectric alternative projects that ENEE can select to satisfy future energy requirements.

WASP simulates operation of the electric generating system, incorporating the probability of occurrence of dry years and the variations in rainfall and resulting available energy from hydroelectric plants within a year. Based on projections of peak demand and retirements of existing capacity, the timing, type, and number of plant additions are selected by the code to minimize the cost of electricity supply and to meet demand and reliability constraints.

II. INPUT DATA

Computer modeling has just begun, and results reported here are preliminary. Many data will be varied parametrically during sensitivity tests, especially data on increases in peak energy demand and costs of the alternatives.

All data were obtained in cooperation with ENEE. The most important data are projected increases in peak energy demand and the characteristics of the alternatives. Projections of peak demand are based on a recently completed study by ENEE, which projects energy requirements in GWh per year. It was assumed that peak demand would increase at the same rate as energy requirements. ENEE's projections go through 1992; beyond 1992, a 5.1% per year increase was used. In future analysis to be completed in the near term, a different set of projections obtained from ENEE that go through 2007 will be used. These projections increase at a faster rate than 5.1% in later years.

Data on the hydroelectric project alternatives were obtained from a Chas. T. Main International, Inc. SEI report entitled "Updating of Honduras Hydroelectric Potential." The 1983 costs in this report were updated to 1987 dollars using a cost escalation factor for hydroelectric projects published by the U.S. Bureau of Reclamation. The net result of the cost escalation was 9% increase in hydroelectric costs between 1983 and 1987. ENEE is presently conducting feasibility studies on their most promising hydroelectric alternatives--Remolino and Naranjito. When these studies have been completed, a more accurate evaluation of the hydroelectric options will be feasible.

The costs of geothermal development at Platanares (Table F-I) were assumed to be equivalent to the cost of development of Miravalles II in Costa Rica--an assumption recommended by Ing. Gustavo Calderón of the IDB. The costs are based on final bids for development of the Costa Rican geothermal field. Ing. Calderón felt that they were adequate to use until more detailed data are obtained through feasibility studies at Platanares. Costs of the 20- and 30-MW plants were scaled from the cost of development of the 55-MW plant using factors obtained from previous bids to the IDB and the Instituto Costarricense de Electricidad for construction of 20-, 30-, and 60-MW plants at Miravalles.

The 10-MW plant differs from the other three geothermal options because it uses binary-cycle, wellhead generators that can operate with fluids of a lower temperature. Thus, the 10-MW plant does not require development of the deep reservoir where the higher temperature fluids reside. Drilling costs should be lower. The cost of the 10-MW generator at Platanares was obtained from a company that manufactures wellhead generators, Ormat. The generator cost shown includes the price of all equipment and the controllers for the wellhead generators ($800/kW) plus the cost of the transformer, the substation, cooling, engineering, etc. (an additional $500-$900/kW). To be conservative, the upper limit of $1,700/kW was used for the "generator" costs. Two alternatives were possible for the drilling costs. Initial estimates from Swissboring indicated that a 500-m-deep well with a capacity of 2 MW would cost $600K. To provide 10 MW of generating capacity, five wells plus one standby well are required. Well costs would thus be $3,600K. However, scaling the well costs from the 55-MW plant at Miravalles results in significantly lower well costs--$1,700K. Since the Miravalles costs are from competitive bids, it was assumed that competitive bidding for the Platanares field would result in costs significantly less than $600K per well. Between 1985 and 1987, drilling cost bids at Miravalles decreased by 40%, showing that the current competitive market for drilling can result in lowered costs. For our preliminary evaluation, we have used the costs scaled from the 55-MW plant.

All costs for each hydroelectric and geothermal alternative include the cost of the transmission line to the nearest point in the grid. Transmission line costs have not been added to the thermal alternatives at this time because it was assumed that a thermal plant will be constructed close to the grid and connection costs will be minimal. Costs were divided into foreign and domestic

components. The foreign/domestic split was obtained from the final distribution of costs for the El Cajón project--74% foreign and 26% domestic. The same ratio was applied to the cost of the transmission lines. The foreign component of the geothermal plant costs is--80%--and is based on the proportion used by the IDB for Miravalles. The cost split for the thermal alternatives are also from the IDB.

In accordance with conventions of the development banks, the domestic costs are discounted by a shadow-price factor to account for the fact that the real value of labor in the Honduran economy is less than its nominal value. The Honduran shadow-price factor for skilled labor, engineering and administration, and warehouses and shipping is 0.7410; for national materials, it is 0.9040 on a scale where the shadow price of foreign exchange equals 1.0. It was assumed that most of the domestic costs will be in the form of labor and shipping, so the 0.7410 factor was used. An initial approximation of the levelized costs for the hydroelectric and geothermal alternatives are shown in Table F-II. These data are used to rank the hydroelectric options from least to most expensive. It is apparent that geothermal energy may be significantly less costly to develop than the hydroelectric alternatives.

For this preliminary analysis, the same thermal alternatives used by the IDB in Costa Rica were used in Honduras. These include a 50-MW fuel/oil-burning plant, a 50-MW gas turbine, a 56-MW coal plant, and a 110-MW coal plant. With the exception of coal, which is not marketed to a significant degree in Honduras, actual present Honduran fuel costs were used in the analysis. Cost data for the thermal options are shown in Table F-III. These are not levelized costs and are not directly comparable to the costs in Table F-II.

III. PRELIMINARY RESULTS

The goal of the economic prefeasibility study is to determine the benefits of geothermal development of the Platanares field by comparing it to all of the alternatives and to determine an optimal expansion plan for ENEE. The immediate objective of this appendix is to estimate the benefits of development of the shallow reservoir, amounting to a capacity addition of 10 MW by as early as 1991. In order to evaluate the benefits of the 10-MW plant, WASP results

that include the possibility of installing a 10-MW plant in 1991 are compared with results that do not include a 10-MW plant as an option. All other data remain the same. Given the input peak demand, operating characteristics of current plants, and future alternatives, WASP selects the set of plants from among the alternatives as needed that minimizes the cost of supplying electricity. Table F-IV shows the preliminary results. The column of numbers under the plant type symbols indicates the number of plants of a given type that are selected in a particular year. For example, the "1+" under the GEOT column on the far right signifies that the first geothermal plant was selected in 1991 and the "+" signifies that another plant of the same type would possible be desirable to minimize costs. The user specifies the date of availability of the various plants and the type of thermal plants that are an option. In this preliminary analysis, the thermal options were limited to the most economic ones--the coal plants and the 50-MW gas turbine. The present value cost of supplying electricity from 1988 through 2008 is approximately $621,900K if the 10-MW plant is included and is $643,400K if the 10-MW plant is not included. (These numbers are the value of the objective function in 2008 from Tables F-IVA and F-IVB, respectively.) The net difference, $21,500K, is thus the present value of the reduction in costs afforded by installing the 10-MW plant.

An initial estimate of present value capital and operation and maintenance (O&M) costs of the 10-MW plant over the 18 years of the study period in which it operates (1991 through 2008) yields a cost of $17,878K capital plus $2,340K of capitalized O&M expenses, totaling $20,218K. This present value cost is less than the reduction in operating costs that ENEE could experience from installing the plant ($21,500K). In addition, operating at an 80% capacity factor, the plant will generate 70,080 MWh/yr of electricity. At an electricity price of $0.09/kWh, the present value of this electricity over 18 years of operation is $45,725K. According to this preliminary analysis, the value of the electricity produced plus the savings in cost of operation far outweigh the cost of the 10-MW plant.

The cost savings computed for the 10-MW plant are based on simulations that will need to be adjusted in the future to decrease the loss-of-load probability (LOLP) to 0.5 to 1%. An LOLP is the number of days per year, expressed as a percentage, when the available generation is expected to be unable to meet the

system load. As a result, unserved energy costs are incurred. Owing to the specification of hydrology conditions in the preliminary analysis, which assumes that the hydrology of the alternatives is similar to that of Lake Yojoa, significant unserved energy costs are being incurred, particularly in the early 1990s. Unless ENEE recommends changes in the specification of the hydrologic conditions, reducing the LOLP to more acceptable levels, required for an optimal solution, is likely to require the addition of more thermal peaking units to serve during dry periods. In other words, the results presented here cannot be considered final. However, a simple examination of cost data in Table F-II shows that present estimates of geothermal and hydroelectric costs favor the development of geothermal plants. WASP selects the 10-MW geothermal plant in the first year that it is available, 1991, indicating that operating costs can be minimized through construction of this plant.

TABLE F-I. GEOTHERMAL PLANT COSTS IN THOUSANDS OF 1987 US DOLLARS UNLESS OTHERWISE NOTED

	10 MW			20 MW			30 MW			55 MW		
	LOCAL	FOREIGN	TOTAL	LOCAL	FOREIGN	TOTAL	LOCAL	FOREIGN	TOTAL	LOCAL	FOREIGN	TOTAL
Eng. & Admin.				1431.80	2202.41	3634.21	2202.77	3388.32	5591.09	3671.28	5647.20	9318.48
Land	3.78	0	3.78	7.37	0	7.37	11.34	0	11.34	18.89	0	18.89
Civil Works				1229.91	220.08	1449.99	2342.69	419.20	2761.89	2928.36	524	3452.36
Wells	0	1701	1701	0	3231.90	3231.90	0	7144.20	7144.20	0	17010	17010
Generator	3275.22	12580	15855.22	2308.87	14945	17253.87	2800.92	18130	20930.92	3785.03	24500	28285.03
Pipes				977.24	1265	2242.34	1265.97	1638.75	2904.72	2221.00	2875	5096.00
Transmission Lines	65.65	252	317.65	65.65	252	317.65	65.65	252	317.65	189.92	729.30	919.22
Total	3344.65	14533	17877.65	6020.84	22116.39	28137.23	8689.23	30972.47	39661.81	12814.49	51285.50	64099.99
Dollar per kw	334.47	1453.30	1787.77	301.04	1105.82	1406.86	289.64	1032.42	1322.06	232.99	923.66	1165.45

TABLE F-II. COST OF HYDROELECTRIC AND GEOTHERMAL PLANT ALTERNATIVES IN 1987 US DOLLARS PER kW UNLESS OTHERWISE NOTED

PLANT	CAPACITY (MW)	AVERAGE ENERGY (GWh/YR)	CRF[a]	CAPACITY FACTOR	CAPITAL COST FOREIGN	CAPITAL COST DOMESTIC	TOTAL COST ($/kW)	O&M ($/kW-YR)	LEVELIZED COST ($/kW-YR)
Naranjito	72	411	0.12	0.65	2158	416	2574	3.72	483
Raity 1	403	1236	0.12	0.35	1175	306	1481	3.72	522
Sico 1-2	85	491	0.12	0.66	2559	666	3225	3.72	597
Sico 1	156	480	0.12	0.35	1768	460	2228	3.72	778
Cayetano	118	669	0.12	0.65	2530	659	3189	3.72	602
Sico 2	122	701	0.12	0.66	2559	666	3225	3.72	600
Remolino	125	550	0.12	0.50	1504	392	1896	3.72	464
Raity-Cay	250	1188	0.12	0.54	1633	425	2058	3.72	466
Guyamel	8.10	33	0.12	0.47	1115	290	1405	3.72	374
Huyuma	8	34	0.12	0.49	2087	543	2630	3.72	664
Cerro Mal	230	1305	0.12	0.65	2120	552	2672	3.72	505
Sico 1+2	207	1193	0.12	0.66	2559	666	3225	3.72	599
Cay+Raity	368	1857	0.12	0.58	1921	500	2421	3.72	515
GE-55	55	389	0.13	0.81	932	233	1165	32.28	224
GE-30	30	210	0.13	0.80	1032	290	1322	32.28	251
GE-20	20	140	0.13	0.80	1106	301	1407	32.28	265
GE-10	10	70	0.13	0.80	1453	334	1788	32.28	325

[a]Capital Recovery Factor for life of plant and interest rate equal to 12%. Life of hydroelectric plants is 40 years; of geothermal plants, 25 years.

TABLE F-III. INPUT DATA ON THERMAL PLANTS

NO.	NAME	NO. OF SETS	MIN. LOAD (MW)	CAPA-CITY (MW)	HEAT RATES (kcal/kWh) BASE LOAD	HEAT RATES (kcal/kWh) AVGE INCR	FUEL COSTS (ℓ/Mkcal) DMSTC	FUEL COSTS (ℓ/Mkcal) FORGN	FUEL TYPE	FAST SPIN RES (%)	FOR (%)	DAYS SCHL MAIN	MAIN CLAS (MW)	O&M (FIX) ($/kWh)	O&M (VAR) ($/MWh)	CAPITAL COSTS ($/kW) LOCAL	CAPITAL COSTS ($/kW) FOREIGN
1	G-32	0	32	32	3879	3349	603.0	2515.0	3	0	20.0	30	50	0.13	0.94	165.5	461.9
2	G-50	0	13	50	3890	2755	603.0	2515.0	3	10	20.0	15	50	0.13	0.81	222.4	486.0
3	B-52	0	13	50	3861	2712	603.0	2515.0	3	10	20.0	15	50	1.39	2.99	306.5	665.5
4	C056	0	24	56	3436	2707	0	667.0	4	10	10.0	30	60	2.67	2.39	103.3	1670.4
5	C110	0	44	110	3200	2500	0	667.0	4	10	15.0	45	110	1.78	3.15	91.8	1495.0
6	STEA	0	75	75	2734	2734	141.0	1549.0	0	0	15.0	45	110	1.78	3.15	74.0	1570.0
7	MSD	0	25	25	2555	2555	141.0	1549.0	0	0	18.0	55	25	5.30	8.80	62.0	1315.0
8	CT	0	25	25	3931	3931	603.0	2515.0	1	0	12.0	36	25	1.16	3.18	26.0	551.0

TABLE F-IV. PRELIMINARY RESULTS OF DYNAMIC OPTIMIZATION

A. CASE THAT INCLUDES 10-MW GEOTHERMAL PLANT

SOLUTION #1 VARIABLE ALTERNATIVES BY YEAR

-- PRESENT WORTH COST OF THE YEAR (K$) -- OBJ FUN LOLP

YEAR	CONST	SALVAL	OPCOST	ENSCOST	TOTAL	(CUMM.)	(%)	G-32	G-50	B-52	C056	C110	STEA	MSD	CT	HYDR	GEOT
2008	0	0	7385	394	7780	621873	1.491	0	5	0	4*	1	0	0	0	1	3+
2007	3672	2800	7157	103	8131	614093	0.517	0	5	0	4+	1	0	0	0	1	3+
2006	20266	14223	7425	178	13646	605962	0.715	0	4	0	4	1	0	0	0	1	3+
2005	4606	2641	8072	1020	11058	592316	2.187	0	4	0	4	0	0	0	0	1	3+
2004	0	0	7621	1452	9073	581259	3.095	0	3	0	4	0	0	0	0	1	3+
2003	16202	7933	7355	961	16586	572186	1.929	0	3	0	4	0	0	0	0	1	3+
2002	6471	2323	7724	1121	12993	555600	2.021	0	3	0	3	0	0	0	0	1	3+
2001	0	0	7181	1648	8830	542607	2.387	0	2	0	3	0	0	0	0	1	3+
2000	22763	7706	6955	1175	23187	533777	1.934	0	2	0	3	0	0	0	0	1	3+
1999	25495	7612	7552	2284	27719	510591	2.614	0	2	0	2	0	0	0	0	1	3+
1998	11402	2770	8452	2892	19975	482872	2.833	0	2	0	1-	0	0	0	0	1	3+
1997	11404	1482	9921	7180	27023	462896	9.150	0	2	0	1	0	0	0	0	1	2+
1996	23115	4184	8305	9759	36996	435873	10.522	0	1	0	1	0	0	0	0	1	2+
1995	0	0	10495	24769	35264	398877	17.218	0	1	0	1	0	0	0	0	1+	1-
1994	16022	695	10925	20647	46899	363614	15.172	0	1	0	1	0	0	0	0	1+	1
1993	56088	7643	7474	36800	92720	316714	19.525	0	0	0	1	0	0	0	0	1+	1+
1992	0	0	8010	53326	61336	223994	24.982	0	0	0	0	0	0	0	0	0	1+
1991	11362	860	8114	43351	61967	162659	20.144	0	0	0	0	0	0	0	0	0	1+
1990	0	0	8720	40823	49543	100692	18.937	0	0	0	0	0	0	0	0	0	0
1989	0	0	14117	14152	28268	51149	8.842	0	0	0	0	0	0	0	0	0	0
1988	0	0	12529	10351	22881	22881	4.325	0	0	0	0	0	0	0	0	0	0

"CONST: = Construction costs.

"SALVAL" = Salvage value.

"OPCOST" = Operating costs.

"ENSCOST" = Unserved energy cost (valued at $0.50/kWh).

"OBJ FUN" = Cost of supplying energy--WASP selects a plan to minimize this.

"LOLP" = Loss of load probability as a percentage of number of days per year.

Plants allowed for consideration: G-50 (gas turbine, 50 MW); C056 and C0110 (56- and 110-MW coal plants); HYDR (hydroelectric plants from Table F-II, listed in order from least to most expensive on a levelized $/kW basis); and GEOT (geothermal plants). The numbers under the plant types indicate the number of plants of the above type that have been selected by WASP. + signifies that more plants of this type are desirable for a given year; - signifies that less plants may be desirable.

B. CASE THAT DOES NOT INCLUDE 10-MW GEOTHERMAL PLANT

SOLUTION #1 VARIABLE ALTERNATIVES BY YEAR

-- PRESENT WORTH COST OF THE YEAR (K$) -- OBJ FUN LOLP

YEAR	CONST	SALVAL	OPCOST	ENSCOST	TOTAL	(CUMM.)	(%)	G-32	G-50	B-52	C056	C110	STEA	MSD	CT	HYDR	GEOT
2008	16156	14356	6487	193	8471	643391	0.858	0	4	0	4+	2	0	0	0	1	2+
2007	3672	2800	7302	600	8774	634920	1.835	0	4	0	4+	1	0	0	0	1	2+
2006	0	0	6991	766	7757	626145	2.006	0	3	0	4	1	0	0	0	1	2+
2005	22698	14139	6924	420	15903	618388	1.237	0	3	0	4	1	0	0	0	1	2+
2004	0	0	8028	1527	9555	602485	2.587	0	3	0	4	0	0	0	0	1	2+
2003	5778	2441	7788	1149	12274	592930	2.126	0	3	0	4	0	0	0	0	1	2+
2002	18147	7866	7226	1096	18604	580656	2.006	0	2	0	4+	0	0	0	0	1	2+
2001	0	0	7712	1914	9626	562053	2.562	0	2	0	3	0	0	0	0	1	2+
2000	8117	2042	7507	1449	15031	55247	2.162	0	2	0	3	0	0	0	0	1	2+
1999	25495	7612	6764	2241	26888	537396	2.595	0	1-	0	3+	0	0	0	0	1	2+
1998	10051	2442	7194	2837	17640	510508	2.810	0	1-	0	2	0	0	0	0	1	2+
1997	11404	1482	8523	3687	22131	492868	3.090	0	1-	0	2+	0	0	0	0	1	1+
1996	35458	6418	6931	9363	45334	470737	10.319	0	0	0	2+	0	0	0	0	1	1+
1995	0	0	8460	24307	32767	425403	17.093	0	0	0	2+	0	0	0	0	1+	0
1994	44931	6941	8889	20104	66983	392636	15.051	0	0	0	2+	0	0	0	0	1+	0
1993	56088	7643	7686	42220	98351	325653	21.064	0	0	0	1	0	0	0	0	1+	0
1992	0	0	8582	59622	68205	227302	26.459	0	0	0	0	0	0	0	0	0	0
1991	0	0	8141	50264	58406	159097	22.064	0	0	0	0	0	0	0	0	0	0
1990	0	0	8720	40823	49543	100692	18.937	0	0	0	0	0	0	0	0	0	0
1989	0	0	14117	14152	28268	51149	8.842	0	0	0	0	0	0	0	0	0	0
1988	0	0	12529	10351	22881	22881	4.325	0	0	0	0	0	0	0	0	0	0

"CONST: = Construction costs.
"SALVAL" = Salvage value.
"OPCOST" = Operating costs.
"ENSCOST" = Unserved energy cost (valued at $0.50/kWh).
"OBJ FUN" = Cost of supplying energy--WASP selects a plan to minimize this.
"LOLP" = Loss of load probability as a percentage of number of days per year.

Plants allowed for consideration: G-50 (gas turbine, 50 MW); C056 and C0110 (56- and 110-MW coal plants); HYDR (hydroelectric plants from Table F-II, listed in order from least to most expensive on a levelized $/kW basis); and GEOT (geothermal plants). The numbers under the plant types indicate the number of plants of the above type that have been selected by WASP. + signifies that more plants of this type are desirable for a given year; - signifies that less plants may be desirable.

APPENDIX G

SUMMARY OF RESULTS OF NATURAL-SOURCE ELECTRICAL STUDIES BY THE U.S. GEOLOGICAL SURVEY AT PLATANARES, HONDURAS, WITH RECOMMENDATIONS

D. B. Hoover
U.S. Geological Survey

Work performed by the U.S. Geological Survey at the Platanares geothermal site, Honduras, consisted of 7 multifrequency telluric lines and 10 audio-magnetotelluric (AMT) soundings. Seven of the AMT soundings were made on one of the dipoles of each telluric line to have a measure of apparent resistivity as reference for each line. The telluric lines covered the area of principal interest at Platanares and are shown in the accompanying Fig. G-1. The telluric surveys were made to identify low resistivity regions at Platanares that might be associated with thermal waters below the surface and to identify major faults that may be controlling the flow of thermal water. Dipole spacing on the telluric lines was 125 m.

Resistivities observed in the area are very low, generally under 10 ohm-m below the surficial deposits, and agree with prior DC electrical studies. This meant that the depth of exploration was not as deep as had been desired. The maximum depth of exploration was not over 300 m in most places, so lithologies beneath the Tertiary Padre Miguel Group would not have been seen on most of the lines. Tertiary andesite crops out near line 4 and the north end of line 5, so they should have been sampled by the EM signals. Unaltered andesites would be expected to have high resistivities, but none were observed on either line 4 or 5. This suggests that the andesites in the area of line 4 have been fractured and altered.

Variations in resistivity along the telluric lines were better than 10 to 1. Assuming that the EM data were sampling principally the Padre Miguel Group, these variations are inferred to reflect the effects of faulting and the presence of geothermal fluids. Figure G-2 shows a resistivity map derived from the AMT and telluric data for the survey area using the 7.5-Hz data. The lowest frequency used in the telluric survey was 7.5 Hz, so the map represents the apparent resistivity changes at the greatest depth we were able to sample. Because the depth exploration is a funciton of both resistivity and frequency, this map does not represent a constant depth horizon. Two areas of very low resistivities are seen in Fig. G-2. One area, under 1.8 ohm-m, corresponds to an area along the Quebrada del Agua Caliente where hot springs are generally unmixed with surface water. The presence of the unmixed hot springs suggests that thermal waters in the area are rising directly along relatively permeable paths from a deeper reservoir. The electrical data are consistent with this,

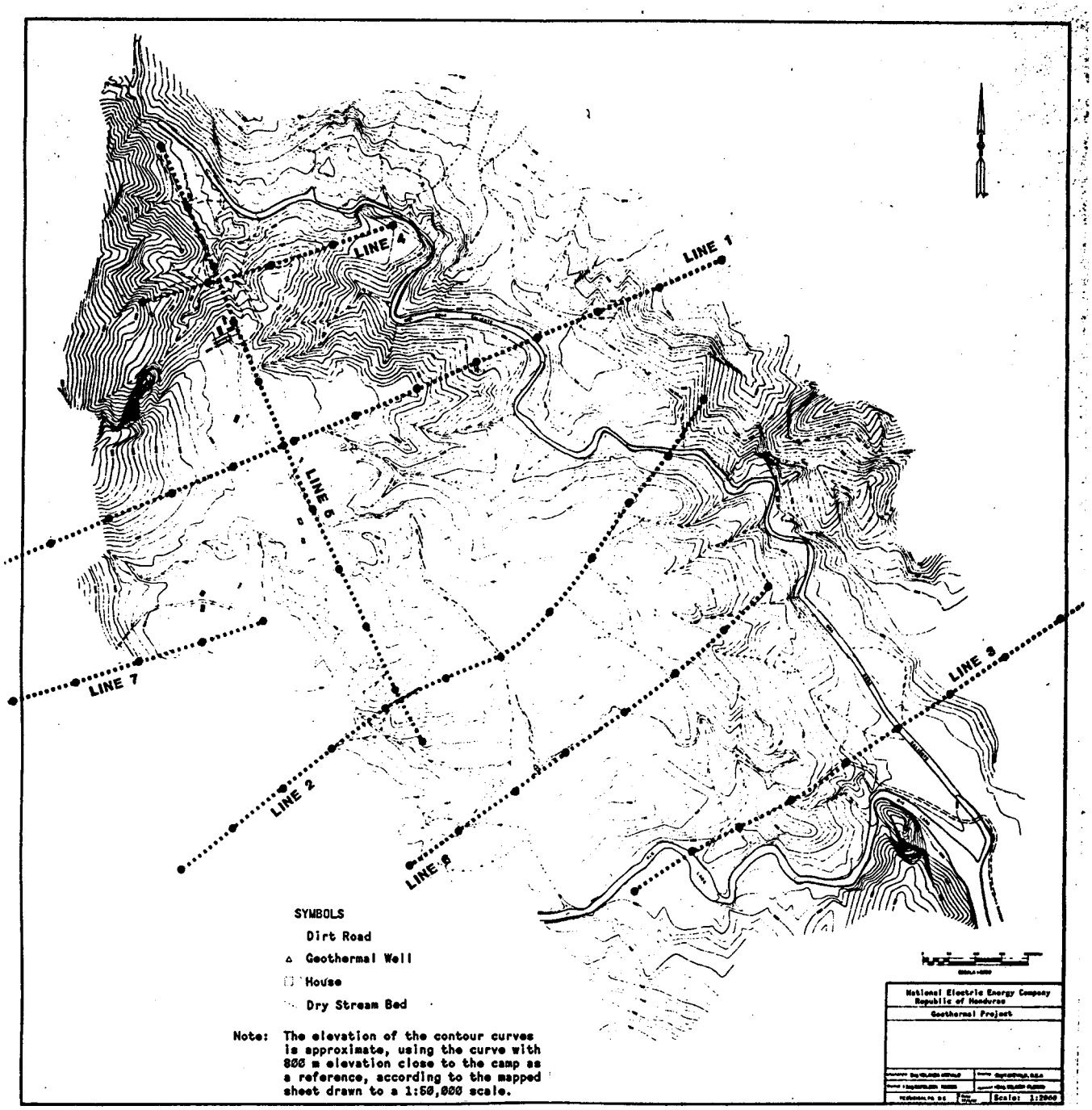


Figure G-1. Location of the telluric lines at Platanares.

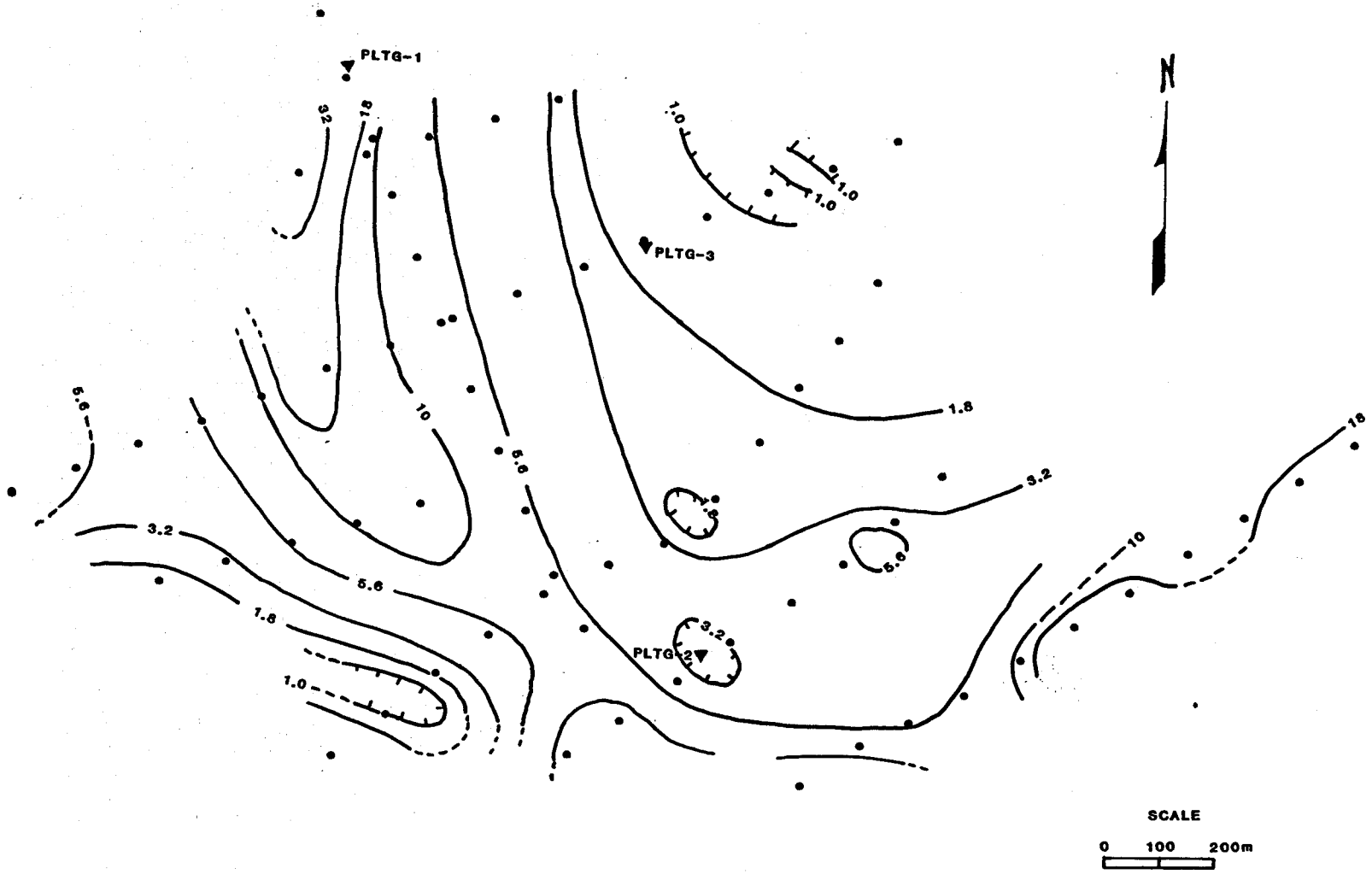


Figure G-2. Platanares resistivity map at 7.5 Hz.

indicating that increased porosity and/or higher salinity and/or higher temperature fluids are present in the area.

Another area of anomalous low resistivity, under 1.8 ohm-m, appears in the southwest part of the mapped area, Fig. G-2. In this area no significant thermal features are known. Before this study the area was not considered to have much geothermal potential. However, the electrical data suggest that a geothermal system is present or was present at one time.

The resistivity map of Fig. G-2 is not adequate to identify individual faults that have an electrical expression. However, the telluric data, which are discusssed in a complete report on this work, show various narrow conductive zones that are inferred to represent faults. Most, but not all, mapped faults that cross the lines can be identified in the telluric data. A number of inferred faults from geological mapping are not evident in the telluric data, and some faults inferred from the telluric data were not mapped. Faults expressed in the telluric data are believed to be those most available to thermal fluids. The anomalous low resistivity region in the southwest part of the area appears to be related to the intersection or close approach of several large faults.

The resistivity map, Fig. G-2, shows that some parts of the Platanares area have been incompletely sampled. Data are clearly lacking north of well PLTG-1 to La Bufa hot spring. Time and difficulty of access prevented our obtaining data in this region. The major low resistivity area along the Quebrada del Agua Caliente is not closed off on the east. Line 1, Fig. G-1, shows some low resistivities extend at least 375 m east of the Quebrada. Although the land east of the Quebrada would be difficult for entry of drilling equipment, the eastern boundary of the low resistivity feature needs to be determined if the geothermal field becomes commercial. Line 3 defines a southern boundary to the nearer surface features of the main thermal area. The data also suggest that the conductor seen in the southwest part of the area may extend farther northwest. Should other studies indicate that some geothermal potential exists in this region, then additional electrical work should be considered to define the extent of this feature.

Completion of the final report on this work is expected by late January 1988. We recommend that, following completion of the report, the principal investigators at Platanares evaluate and integrate the results with prior data.

There may be sufficient data for siting the next round of drilling. Clearly the electrical data in no way contradict the basic model of the system at Platanares. In this case there would be no need for additional electrical data until after completion of addtional holes.

We, however, recommend that testing of the southwest electrical anomaly be considered in the next round of drilling. If the area is favorable, then communication between production wells here and on the main thermal trend is less likely than between wells on the main trend. This could significantly increase the capacity of the field.