MASTER

LA-10685-MS

UC-66b
Issued: December 1986

Reconnaissance Evaluation of Honduran Geothermal Sites

LA--10685-MS

DE87 003796

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EXECUTIVE SUMMARY

The reconnaissance of potential geothermal resource sites in Honduras is a joint effort by Honduras (Empresa Nacional de Energía Eléctrica) and the United States (Los Alamos National Laboratory and U.S. Geological Survey). The assessment is part of the Central American Energy Resources Project being sponsored by the U.S. Agency for International Development.

In this study, we evaluated six geothermal sites that previous geothermal exploration in Honduras had identified. These sites were ranked for more detailed investigations according to their potential for geothermal energy development.

On the basis of the preliminary geologic and geochemical investigations, three sites warrant detailed investigation for development as sources of electrical energy. Platanares, San Ignacio, and Azacualpa have the necessary combination of high base temperature, sufficient flow of hot fluids, easy access, and proximity to potential energy customers. A fourth site, Pavana, may be a source of direct-use heat.

When these detailed investigations are completed, two sites will be selected for further study by geophysical and drilling techniques, and these results will establish the geothermal potential of the sites. On the basis of these results, decisions can be made by the Honduran government on the potential for future development.

RECONNAISSANCE EVALUATION OF HONDURAN GEOTHERMAL SITES

by

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ABSTRACT

Six geothermal spring sites were selected on the basis of preliminary investigations conducted in Honduras over the last decade and were evaluated in terms of their development potential. Of the six, the Platanares and San Ignacio sites have high base temperatures and high surface fluid discharge rates and appear to have the best potential for further development as sources of electrical power. A third site, Azacualpa, has a high enough base temperature and discharge rate to be considered as a back-up, but the logistical problems involved in geophysical surveys make it less attractive than the two primary sites. Of the remaining three sites, Pavana may be a source of direct-use heat for local agricultural processing. Sambo Creek and El Olivar have either severe logistical problems that would impede further investigation and development or base temperatures and flow rates that are too low to warrant detailed investigation at this time.

I. INTRODUCTION

Geothermal exploration programs in Honduras have been conducted since the late 1970s, when Geonomics, Inc., conducted an initial geologic investigation of hot spring sites in the Pavana region (Geonomics, 1977). Although that program was terminated before completion because of financial problems, the study indicated potential for geothermal development in Honduras. Further studies, funded in part by the United Nations Development Program (UNDP) and conducted by GeothermEx, Inc., indicated an abundance of hot springs throughout Honduras (GeothermEx, 1980). The GeothermEx study identified six sites at which preliminary geochemical analyses of water samples indicated reservoir base temperatures high enough to be considered for electrical power generation. These six sites formed the basis for the current U.S. Agency for International Development (USAID)-Los Alamos National Laboratory-Empresa Nacional de Energía Eléctrica (ENEE) geothermal development program.

II. REGIONAL GEOLOGY

Understanding any geothermal system is difficult without a knowledge of the region's tectonics and stratigraphy. A summary of the regional geology is provided below as a framework for understanding the Honduran geothermal systems investigated thus far.

A. Tectonic Setting

Honduras lies on a portion of the Caribbean tectonic plate called the Chortis block (Fig. 1). This block, which lies on the northwest corner of the Caribbean plate, is composed of Paleozoic and younger continental crust. It is bounded on the north by the Caribbean-Americas plate boundary, consisting of the Bartlett/Cayman trough system and the Motagua and Polochic fault systems. To the west and south, the Cocos plate is moving northeastward from the East Pacific rise and is being subducted under the Caribbean and Americas plates along the Middle America Trench. The Chortis block is terminated on the east and south by a region of younger crust of oceanic affinities in Nicaragua (Malfait and Dinkelman, 1972; Case and Holcombe, 1980). A detailed discussion of the tectonic history of this region is beyond the scope of this report, but the reader is referred to Anderson and Schmidt (1983) and Burkart and Self (1985).

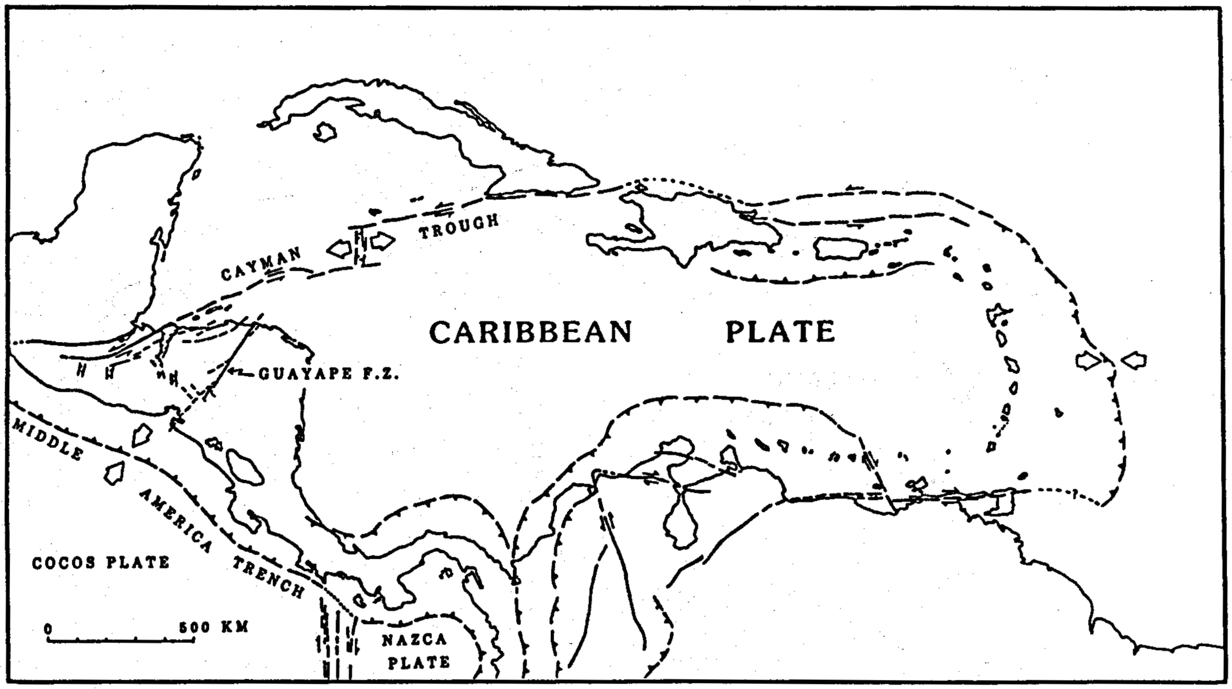

Figure 1. Generalized plate tectonics of the Caribbean region (modified from Case and Holcombe, 1980).

The principal tectonic features within Honduras (Fig. 2) include a number of east-west- to east-northeast-trending faults (Chamelecón, La Ceiba, Aguán) that are subparallel to the sinistral plate boundary and are thought to be part of, or older analogues to, that plate boundary. The Guayape fault of eastern Honduras may also be related to this group of faults (Ritchie and Finch, 1984).

Generally north-trending grabens associated with the "Honduras Depression" cut across Honduras from San Pedro Sula to the Golfo de Fonseca. The faults bounding these grabens as well as a host of other faults throughout Honduras average a northerly strike, but they are stepped along northeast- and northwest-trending faults that are dominantly normal-slip but also have small strike-slip components. Pflaker (1976) suggested that the northwest corner of the Caribbean plate is fragmenting along north-trending extensional features of which the Honduras Depression is the easternmost. The fragmentation results from this portion of the plate being pinned between the Cocos and Americas plates as eastward movement of the Caribbean plate continues (Fig. 1). The initiation and greatest movement of the graben faults are associated with the eruption of the Padre Miguel tuffs in the Miocene and Pliocene, although

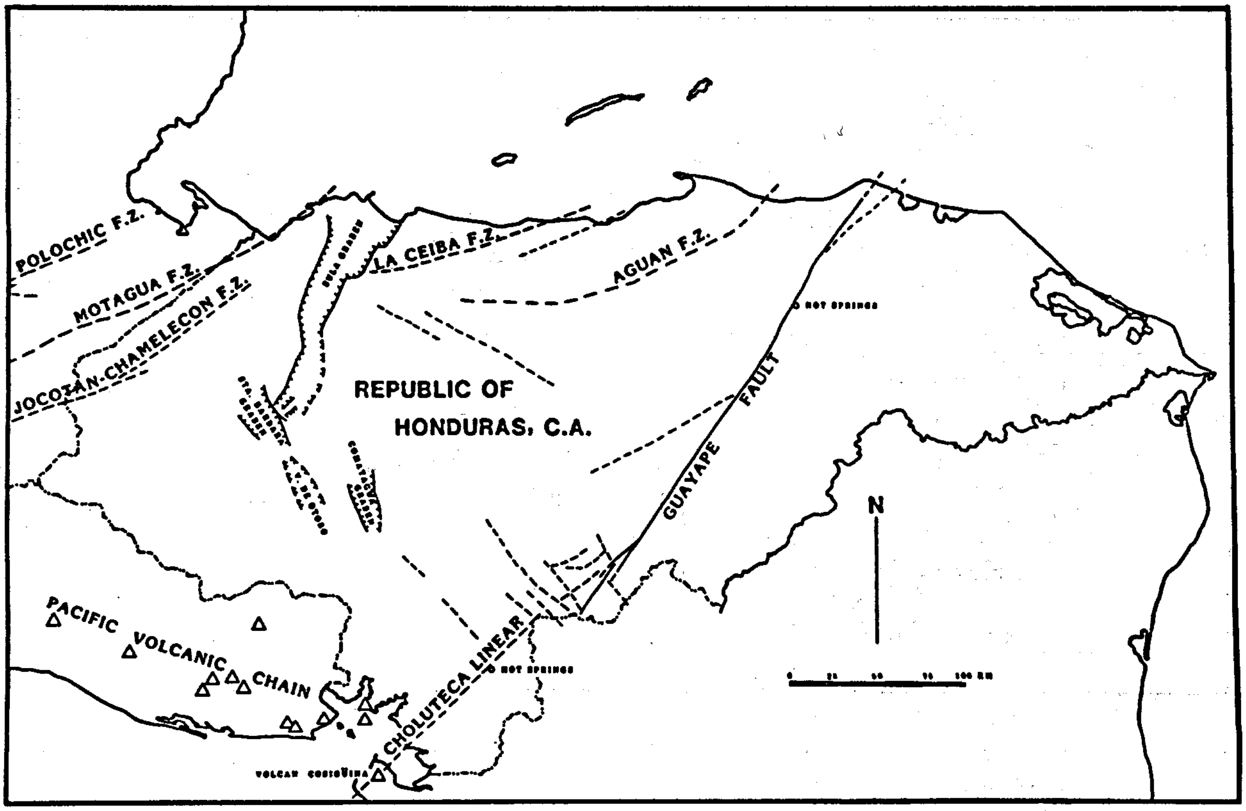

Figure 2. Major tectonic features of Honduras.(This information was supplied by R. Finch, Tennessee Technological University, and A. Ritchie, College of Charleston, 1985.)

minor adjustment on these faults may continue today. The east-west extension responsible for the graben implies a north-trending horizontal principal stress, which would further suggest that a sinistral component of motion is associated with the northeast faults and a dextral component is associated with the northwest faults. In addition to the graben formation and block faulting, this same extension has very likely produced crustal thinning in the region. This regional setting suggests an analogy to the Basin and Range physiographic province of the western United States, where several geothermal fields are being developed.

B. Stratigraphy

The details of the stratigraphy of Honduras are not well known principally because of poor bedrock exposure and closely spaced faulting. The best available description is that of Finch (1981), whose data, along with that of Mills et al. (1967), are reproduced as Fig. 3.

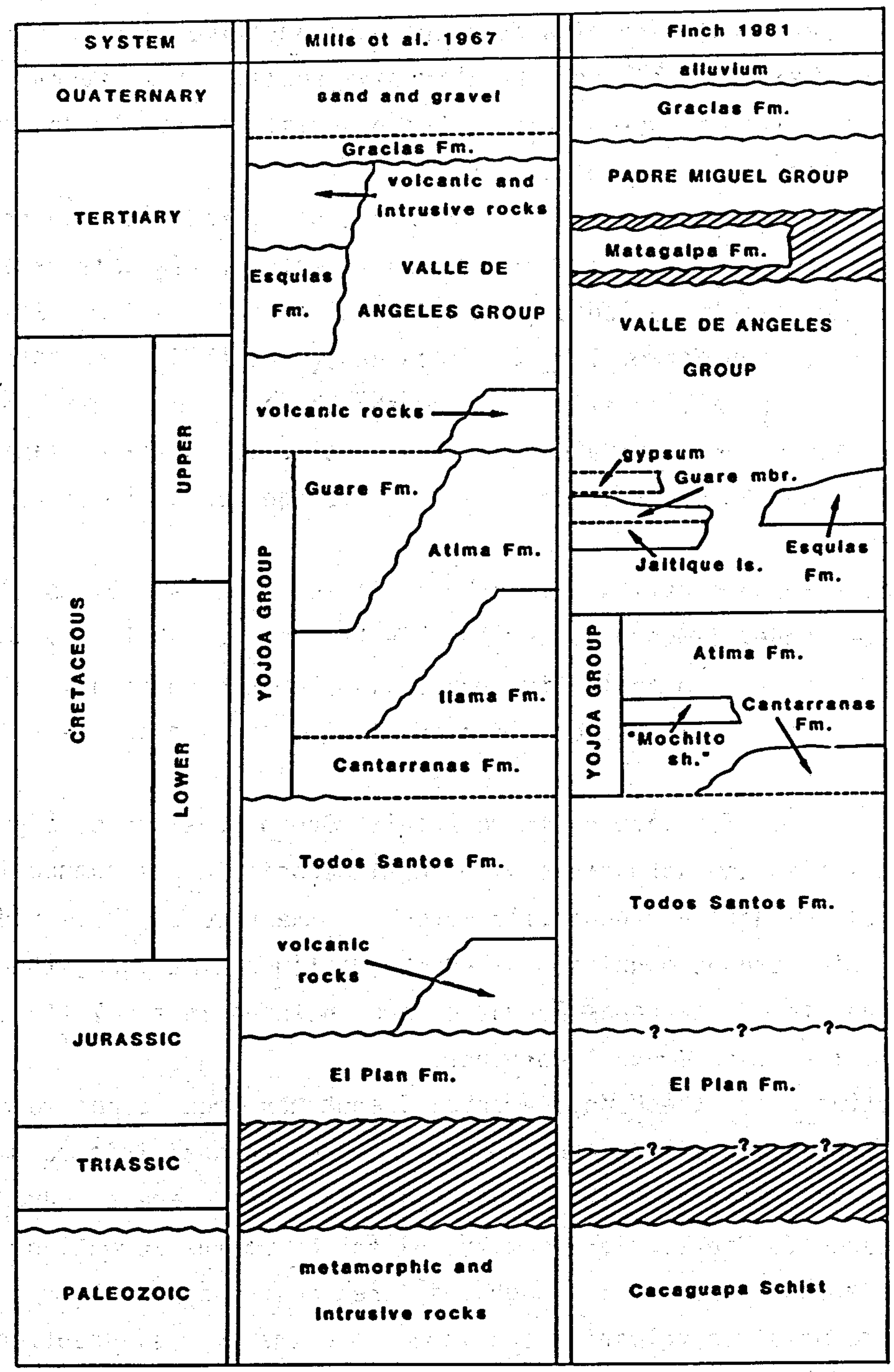

Figure 3. Stratigraphic column for central Honduras (after Mills et al., 1967, and Finch, 1981).

The oldest unit on the Chortis block is a basement complex of low-rank metamorphic rocks consisting of a dominant dark phyllite with lesser amounts of schist, quartzite, carbonate, and intrusive rocks. These rocks have been variously termed the Cacaguapa schist, Petén schist, or simply "basement" and are generally assumed to be Paleozoic.

The basement rocks are overlain by a section of red beds and other clastic units that underlie the Yojoa Group limestone. These strata include the El Plan Formation, the Todos Santos Formation, and the "Agua Fría Formation" (Finch and Horne, 1986). Finch and Horne (1986) propose the name "Honduras Group" for all clastic units on the Chortis block that overlie the crystalline basement and predate the Albian-Aptian-age Atima Formation. Ritchie and Finch (1985) demonstrate a Jurassic age for at least part of the Honduras Group.

The Yojoa Group consists primarily of Atima Formation, up to 1400 m of dark, thickly bedded limestone, and locally the Mochito shale and the Cantarranas Formation, a shaly limestone. The Atima Formation is an excellent marker, for it is the only thick limestone in the section and is a prominent ridge former.

The Cretaceous-Tertiary Valle de Angeles Group consists of a great thickness of red shales and sandstones with conglomeratic layers common in the lower part of the unit and generally absent in the upper. Three additional, relatively thin carbonate units, called the Jaitique Limestone, the Esqúias Formation, and the Cantarranas Formation are included in the Valle de Angeles Group and in the Yojoa Group limestones.

Subduction along the Middle America Trench has been responsible for a long history of volcanism in the Republic. Widespread silicic volcanism appears to have ceased ~10 million years ago, and there are no currently active volcanoes. Mid-Tertiary basalts of the Matagalpa Formation are widespread throughout Honduras, although they are locally absent from the section. At least some basaltic volcanism continued into the time of eruption of the widespread and voluminous silicic tuffs of mid- and late-Tertiary Padre Miguel Group. There is some debate about the maximum and minimum ages of the Padre Miguel Group, but the majority of the tuffs appear to have been erupted in the Miocene and Pliocene. These rocks were erupted onto a surface of considerable relief that was undergoing active block faulting. As a result, the thickness of the tuffs is extremely variable, making projections of the depth to underlying strata difficult, if not impossible.

Some young, possibly Quaternary to Recent basaltic volcanism occurred in Honduras, principally along the Honduras Depression from Tegucigalpa to the north coast. These rocks can be interbedded with Pliocene-Pleistocene clastic sediments and reworked tuffs of the Gracias Formation and multiple units deposited by alluvial processes as block faulting proceeded throughout central Honduras.

C. Summary

The absence of young ($<$1 million years old) silicic volcanism suggests that cooling silicic plutons are not the heat source for geothermal systems in Honduras. The tectonic activity of Honduras is largely influenced by recent graben formation and extensive block faulting. This suggests that the geothermal systems are of the Basin and Range type; that is, the systems are dominated by thin crust and high regional heat flow. In particular, it appears that the heat source for geothermal systems in Honduras is not volcanic in nature.

III. RECONNAISSANCE GEOLOGY AND GEOCHEMISTRY

At the present time, reconnaissance site geology investigations and hydrogeochemical sampling have been completed on all six sites (Fig. 4). Results from these investigations are summarized below.

A. Azacualpa

The Azacualpa site is located $\sim$4 hours' drive north of Tegucigalpa at UTM grid $\sim$843/236. The appropriate map is the San Pedro Zacapa 1:50,000 quadrangle; a geologic map of this quadrangle has also been completed by Finch (1979). To get to the site, proceed north on the Carretera del Norte to a turnoff in the town of Taulabé at UTM grid $\sim$980/234. Travel along a two-lane dirt road to the village of San Pedro Zacapa; then proceed south from Zacapa along a rough dirt track to the village of Azacualpa. The thermal site is $\sim$1.8 km east of the village along the Río Jaitique.

Thermal waters at the Azacualpa site are surfacing along fractures in the Atima Formation associated with the main north-south-trending Zacapa fault and

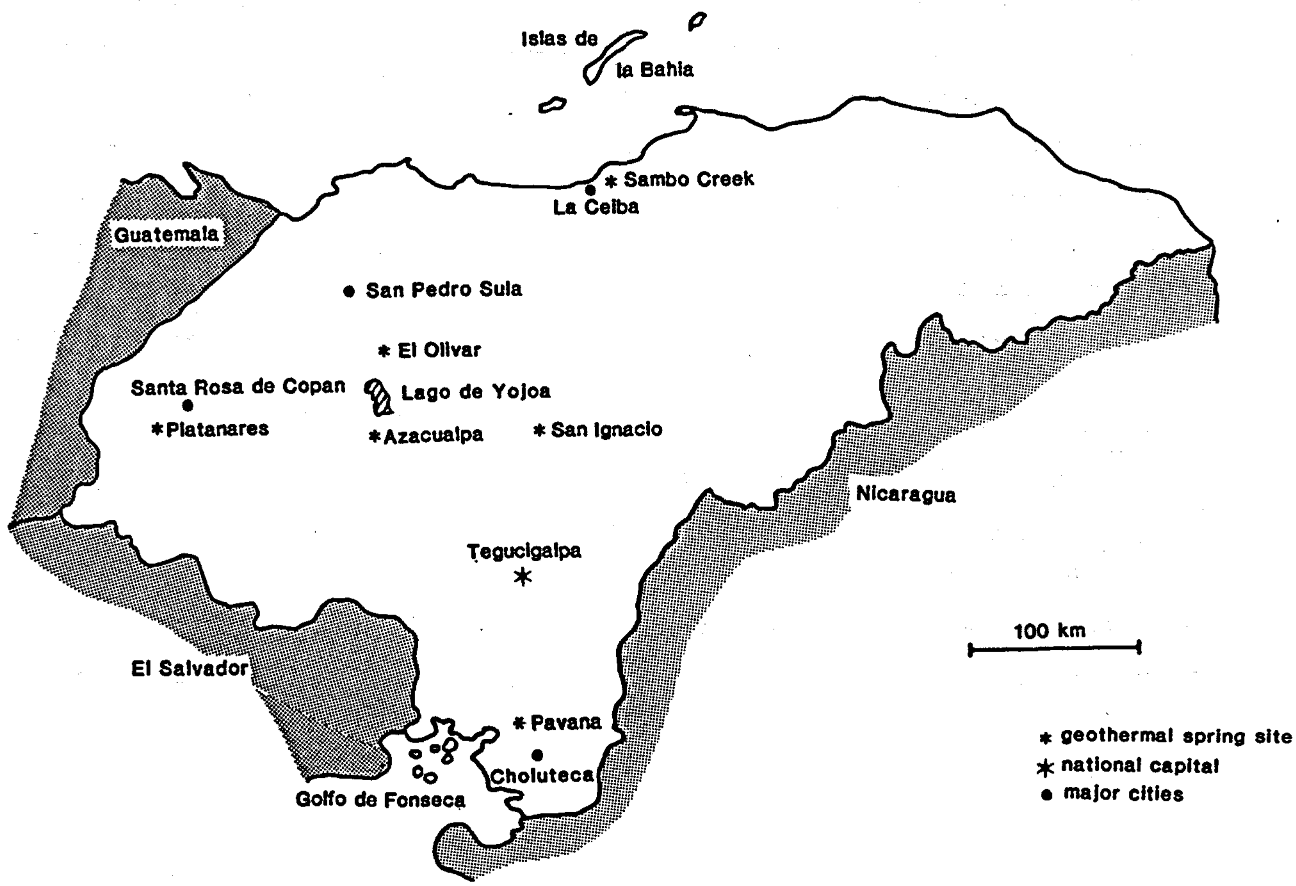

Figure 4. Prime geothermal sites in Honduras.

subsidiary splays. Permeability appears to be related to both these fractures and to formation permeability, which is probably related to the development of solution caves in the Atima Formation. Attitudes of the lower Valle de Angeles Group red beds do not change significantly with increasing distance from the Zacapa fault, suggesting that the fault is not behaving as a listric normal fault at depth. There does not appear to be any significant east-west-trending structure affecting the location of this thermal site (see Eppler et al., 1986, for additional details).

B. Platanares

This site is ~2-1/2 hours south of Santa Rosa de Copân at UTM grid ~927/327. The appropriate topographic map is the Santa Rosa de Copân 1:50,000 quadrangle. To reach the site, drive south from Santa Rosa along the

Carretera del Occidente to the village of Los Arroyos at UTM grid ∼966/623. Proceed north along a very rough 1-1/2-lane dirt road to the villages of La Union in UTM grid square 95/21 and El Corpus in UTM grid square 94/25. Continue on to the village of Platanares at UTM grid ∼924/325. The thermal site can be reached by descending a steep slope into the Quebrada de Agua Caliente between UTM grids ∼927/327 and ∼929/325.

The thermal manifestations are found along faults in tuffs, tuffaceous sedimentary rocks, and lavas of the Padre Miguel Group and between the Paleozoic basement and the Padre Miguel Group rocks. These rocks are silicified near the faults and are often fractured, and they may provide the fracture permeability necessary for the hydrothermal system. The tuffs are overlain by a wedge of terrace gravels up to 60 m thick. The Platanares area contains numerous faults, all of which appear to be extensional. There are four groups of faults (N80°E to N70°E; N30°W to N60°W; N40°E to N65°E; and N0° to N5°W). All of the hot springs at this site are located along faults that trend mostly northwest, northeast, and north (see Heiken et al., 1986, for additional details).

C. San Ignacio

This site is ∼2-1/2 hours north of Tegucigalpa at UTM grid ∼915/248. The appropriate topographic map is the El Porvenir 1:50,000 quadrangle. The quadrangle was mapped by Simonson (1977). To reach the site, take Honduras Route 2 north out of Tegucigalpa to the village of Talanga in UTM grid square 91/92. Take a two-lane dirt road north to the village of Cedros; then proceed east to the village of San Ignacio. Take another dirt road north to the village of Barrosa; then continue an additional 1-2 km farther to the thermal site.

Hot springs are located along a northwest-trending fault scarp at the edge of the Siria Valley, and where north-south-trending faults cross the main northwest fault. The rocks in the area are mostly Paleozoic metamorphic rocks, overlain by patches of Padre Miguel Group tuffs and alluvial deposits. Faulted alluvial fans suggest that movement along several of the faults associated with the spring site continued to latest Quaternary time (see Aldrich et al., 1986, for additional details).

D. Pavana

This site is located ~2 hours south of Tegucigalpa along the Carretera Panamericana at UTM grid ~656/814. The appropriate topographic map is the San Lorenzo 1:50,000 quadrangle. To reach the site, take the Carretera del Sur out of Tegucigalpa until you reach the Carretera Panamericana in the town of San Lorenzo. Proceed east to the village of Pavana. In addition to the main spring site, there are subsidiary springs at UTM grids ~659/819 and ~628/809.

The hot springs at the main spring site in Pavana surface in Tertiary age gravels that are included in an alternating sequence of andesites and rhyolites exposed in several southwest-trending normal fault blocks located northeast and southwest of the spring site. Although the conduits were not observed, it seems likely that the thermal waters are surfacing along similar, southwest-trending normal faults, which parallel the frontal scarps on the fault blocks. Although the actual age of the volcanic rocks exposed in the region is unknown, they appear to be too old to represent leaks from currently active crustal magma systems. Geologic studies by Geonomics (1977) and the UNDP group suggested the presence of three calderas within 7-10 km of the main thermal area. However, no field evidence suggests the presence of these calderas (see Duffield et al., 1986, for additional details).

E. Sambo Creek

The main spring site at Sambo Creek is approximately 30 minutes' drive east of La Ceiba along a rough two-lane dirt road. The appropriate topographic map is the Jutiapa 1:50,000 map. The trail leading to the spring site intersects the main road at UTM grid ~4015/4530. This trail leads south through steep jungle and meadows to the spring site, which is on the Río Sambo Creek between UTM grids ~062/733 and ~058/729. Access to this site by any truck-mounted equipment would be impossible without additional road construction in steep jungle terrain.

The springs at the Sambo Creek site surface in the bed of the creek at boiling temperature. The local geology is obscured by jungle, but a brief reconnaissance indicates that the thermal waters reach the surface along high-angle faults that cut Paleozoic schistose rocks and intermediate composition intrusive rocks.

F. El Olivar

The El Olivar site is located in the central portion of the Sula graben, ~5 hours' drive north of Tegucigalpa. The appropriate topographic map is the Río Lindo 1:50,000 map. To reach the site, take the Carraterra del Norte to the turnoff to La Barca, in UTM grid square 00/71. Take Department Highway 61 toward El Progreso to a one-lane dirt road in UTM grid square 04/74. The springs are located at the base of a prominent normal fault scarp trending N30°E, which is east of the springs, between UTM grids ~062/733 and ~058/729. A subsidiary spring site is located at UTM grid ~977/705.

Except for an unpublished Ph.D. dissertation by Zuniga-I. (1975), the geology in the area of this site is unknown, and no surface exposures of bedrock were accessible in the limited time available during the reconnaissance visit. The physiography of the local area and the site's location in the Sula graben suggest that the thermal waters are surfacing along normal faults related to the formation of the graben.

G. Preliminary Results of Hydrogeochemical Surveys

The six areas described above were sampled by the Los Alamos-ENEE hydrogeochemical team in May 1985 (Goff et al., 1985; Truesdell et al., 1985; Goff et al., 1986). The geothermal areas sampled do not discharge acid-sulfate waters, nor do they possess high-pressure, superheated fumaroles characteristic of vapor-dominated geothermal systems. Instead, the geothermal fluids are neutral to alkaline in pH and are best classified as $Na\text{-}HCO_3\text{-}SO_4\text{-}Cl$ waters. The systems with higher temperatures generally deposit silica sinter. These characteristics resemble many hot-water-dominated geothermal systems of the Basin and Range province, particularly the high-temperature system at Beowawe, Nevada.

Stable isotope analyses from Honduran ground waters show that pronounced regional isotope variations are caused by the north-to-south weather patterns and terrain variations. Isotope studies indicate that recharge to the systems is localized, although it generally comes from zones of higher elevations adjacent to the geothermal systems sampled.

The present background tritium of Honduran ground waters is 4-4.5 tritium units (T.U.), whereas hot, unmixed geothermal fluids contain 0-0.25 T.U. Using piston flow and well-mixed reservoir models as end members, we estimate the geothermal waters of Honduras to be roughly 32 to 7500 years old, and most likely closer to 2000 years old.

Estimated base temperatures, discharge, and thermal output of the six geothermal areas studied are summarized in Table I.

IV. EVALUATION OF SITES

As of January 1, 1986, Platanares and San Ignacio appear to be the most promising sites for electrical power development, and consequent additional work, with Azacualpa as a possible back-up. The Pavana site shows some potential for development as a source of direct-use heat. At the present time, Sambo Creek and El Olivar are not being considered for further detailed work. These decisions are based on hydrogeochemical survey results and on logistical problems associated with further site development.

A. Geothermometry

The Platanares site has the highest estimated reservoir temperature (∼225°C) of any of the six sites. The San Ignacio and Azacualpa sites (195°C and 180°C, respectively), while having lower reservoir temperatures than Platanares, have temperatures sufficiently high to warrant additional investigations.

TABLE I. Estimated Base Temperature, Discharge Rate, and Thermal Power Output from Geothermal Sites in Honduras (modified from Goff et al., 1986)

	Discharge (ℓ/min)	Base Temp (°C)	Thermal Power (MW)
Platanares	3150	225	45
San Ignacio	1200	190	14
Azacualpa	1200	185	13
Pavana	1000	150	8
Sambo Creek	2000	155	17
El Olivar	200	120	1.3

At this time, the Honduras geothermal program is not concerned with direct-use applications of heat derived from these sites, but developing direct-use heat from the Pavana site might be considered in the future. Logistical considerations detailed below suggest that, at the present time, development of the El Olivar and Sambo Creek sites may be impossible for power generation or direct use.

B. Logistical Considerations

Of the five sites with reservoir base temperatures lower than 200°C, Azacualpa and Sambo Creek have important logistical problems that affect further investigations and future development. The terrain in the vicinity of Azacualpa will pose significant problems for completing and interpreting the results of geophysical surveys, and the presence of a presumably thick section of Valle de Angeles shale in the Azacualpa area will present additional problems in interpreting the results of resistivity surveys.

Further investigations at the Sambo Creek site will be hampered by terrain, climate, and inaccessibility of the site to heavy equipment. The terrain in the vicinity of the site is steep and heavily vegetated; detailed investigations of its geology will be difficult because little outcrop is exposed. In addition, moving equipment for geophysical investigations and drilling will be impossible without constructing suitable roads, which will be difficult, time consuming, and expensive.

V. FUTURE WORK

Future work for the Honduras geothermal project should contribute directly to helping ENEE decide whether to continue development of geothermal electric power in Honduras. In particular, the site of the thermal reservoir must be located and described, its size and potential power output determined, and its longevity estimated.

Geophysical surveys are scheduled to begin in the spring of 1986, and drilling to establish the local geothermal gradient is scheduled to begin in mid-1986. We suggest that these studies concentrate initially on the Platanares site, with additional work on the San Ignacio site to take place only after completion of investigations at Platanares. For this project, additional work on the remaining four sites should be undertaken only if it becomes necessary to develop a back-up to Platanares or San Ignacio.

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