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ABSTRACT

The initial phase of a geothermal resource assessment of Honduras is essentially complete. Reconnaissance scale geological and geochemical investigations were performed at six previously identified sites to determine relative potentials for electricity generation or direct heat use. Two of the six sites were eliminated because of low potential for the production of electricity and detailed geological and geochemical work was concentrated at the remaining four sites. After an evaluation of new data, two sites (Platanares and San Ignacio) were selected for detailed geophysical surveys and one (Platanares) for gradient drilling. Very encouraging results were obtained from the drilling and it is apparent that a feasibility phase investigation is warranted at Platanares.

BACKGROUND

Reconnaissance scale geothermal investigations began in Honduras in 1976. Limited geologic, geochemical and geophysical investigations were performed by a commercial geothermal exploration company [1]. From 1979 to 1980, ENEE with assistance from UNDP conducted a country-wide hydrogeochemical study. These studies led to the first identification of areas of geothermal interest in Honduras.

The Honduran Geothermal Resource Development Component is part of the Central America Energy Resources Program (CAERP) at Los Alamos. The CAERP was initiated to assist in improving economic conditions in Central America and help create employment through increased and more efficient utilization of the region's energy and natural resource endowment.

INTRODUCTION

In 1985, the Empresa Nacional de Energia Electrica de Honduras (ENEE), the Los Alamos National Laboratory (Los Alamos) and the U.S. Geological Survey (USGS) began a geothermal resource assessment of Honduras, C.A. Funding for this assessment work was provided by the U.S. Agency for International Development (USAID). Shortly thereafter, the ENEE also began a geothermal assessment in cooperation with an Italian team funded by the United Nations Development Program (UNDP). The ENEE has established a coordinating committee comprising members from ENEE, Los Alamos and the Italian team to prevent duplication of effort and to ensure cooperation. The USAID funded program has as its objectives a country-wide geothermal assessment and more site-specific investigations at six previously identified geothermal areas. Because ENEE must make a decision by early 1988 on the feasibility of developing geothermal energy for the production of electricity in Honduras, much of the effort has been concentrated on the evaluation of the six identified sites. The Italian effort has focused on a reconnaissance evaluation of a large area in central Honduras.
Reconnaissance Investigation of Six Potential Geothermal Sites

Reconnaissance scale geologic and geochemical studies were conducted at all six of the previously identified sites. Results of the geologic studies are presented in a report by Eppler et al. [2]; geochemical results are included in the hydrogeochemical report of Goff et al. [3]. Geologic results indicate that the geothermal manifestations at all six sites are fault controlled. The geothermal systems are not related to young volcanism but are similar to the Basin and Range geothermal resources of the western United States [4]. The major tectonic features of Honduras suggest widespread extension and probable crustal thinning beneath Honduras with high heat flow.

During the reconnaissance scale geochronal studies, water samples were collected from hot springs at all six sites. These samples were analyzed and the results used for geothermometric estimates of the reservoir temperature [3]. These estimates are given in Table 1. It is clear from these results that the Platanares geothermal site has the highest potential for generating electricity; the San Ignacio

Table 1. Summary of Averaged Geothermal Calculations (°C) for Geothermal Sites in Honduras (underlined values represent estimated reservoir temperatures; from Goff et al. [3])

<table>
<thead>
<tr>
<th>Site</th>
<th>Silica</th>
<th>Na-K</th>
<th>Na-K-Ca</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quartz</td>
<td>Quartz</td>
<td>(Fournier)</td>
<td>β=1/3</td>
</tr>
<tr>
<td>Platanares</td>
<td>201</td>
<td>185</td>
<td>183</td>
<td>219</td>
</tr>
<tr>
<td>San Ignacio</td>
<td>178</td>
<td>167</td>
<td>158</td>
<td>200</td>
</tr>
<tr>
<td>Azacualpa</td>
<td>183</td>
<td>171</td>
<td>163</td>
<td>199</td>
</tr>
<tr>
<td>Pavana</td>
<td>151</td>
<td>144</td>
<td>126</td>
<td>152</td>
</tr>
<tr>
<td>Sambo Creek</td>
<td>154</td>
<td>147</td>
<td>130</td>
<td>160</td>
</tr>
<tr>
<td>El Olivar</td>
<td>142</td>
<td>136</td>
<td>115</td>
<td>197</td>
</tr>
</tbody>
</table>

a No steam loss.
b Maximum steam loss.
c Magnesium correction applies only at El Olivar site.
d Continuous steam loss.
e D-Amore and Panichi (1980).
f Norman and Bernhardt (1981).
and Azacualpa sites also have high potential. Pavana, because of its proximity to possible direct heat users, may have potential for such applications. As a result of the early reconnaissance investigations the decision was made not to perform detailed studies at Sambo Creek or El Olivar.

DETAILED INVESTIGATION OF FOUR POTENTIAL GEOTHERMAL SITES

To further narrow down the choice of sites for expensive geophysical surveys and gradient drilling, detailed geologic and geochemical studies were performed at Platanares, San Ignacio, Azacualpa, and Pavana. The geologic studies emphasized detailed geologic mapping with particular attention to the location and attitudes of structures that may be controlling the movement of geothermal fluids. All hot spring locations were mapped and temperatures and flow rates measured. Separate bilingual reports were issued for each of the four sites [5-8]. Detailed geologic maps and cross-sections are presented with each report. The results of the geologic investigations indicated the importance of fracture permeability at all of the sites. Additional water and gas samples were collected at the four sites to better define reservoir temperatures, residence time of fluids within the geothermal systems, the amount of mixing, and the general characteristics of the geothermal fluids. Fluid samples were analyzed for the concentration of cation and anion species and of tritium. Hydrogen and oxygen isotope ratios were also measured in these samples. Gas samples were analyzed for major components and for the isotopic composition of carbon in CO₂. Results of these analyses and interpretations are given in Goff et al. [3] and will only be briefly summarized here. None of the four sites discharge acid-sulfate waters characteristic of vapor-dominated geothermal systems. The geothermal waters are neutral to alkaline and are best described as Na-HCO₃-SO₄-Cl waters. Tritium concentrations indicate a lifetime of fluids in the geothermal system in excess of 500 years. Mixing of hot and cold end-member waters has occurred at Platanares, to a lesser degree at San Ignacio and Azacualpa, but not at Pavana. Silica, cation and gas geothermometers have substantiated the original estimates. Additional water and gas samples were collected at the four sites. The compositions of the fluids from samples from the Platanares site strongly suggest that the fluids equilibrated within the redbeds of the Valle de Angeles Group. An evaluation of the integrated geologic findings and geochemical results indicated that Platanares was clearly the highest potential geothermal site in Honduras. The estimated reservoir temperature of 255°C is high enough for electricity generation, the area of geothermal manifestations is large and there is abundant evidence of high fracture permeability. These results indicate that San Ignacio and Azacualpa have approximately the same potential for electricity generation and Pavana still apparently has potential for direct-heat use.

DETAILED GEOPHYSICS AND GRADIENT DRILLING

After completion of the detailed geologic and geochemical studies at the four potential geothermal sites, the decision was made to proceed with detailed geophysical surveys at two sites (Platanares and San Ignacio) and also measured the geothermal gradient drilling to Platanares. Two geophysical exploration techniques were applied to the evaluation of the Platanares and San Ignacio sites; detailed gravity surveys and self-potential (SP) surveys. These techniques were chosen to provide additional information on the distribution of faults and fractures within the areas and to evaluate the movement of geothermal fluids. Gravity measurements were made at about 500 stations at the Platanares site and at about 570 stations at San Ignacio. Complete and residual Bouguer gravity anomaly maps were constructed at scales of 1:10000, 1:20000 and 1:50000 for each site. These maps are included as part of the geophysics report of Ander et al. [9]. A total of 40 km of data was collected at Platanares; and 52 km of data were collected at San Ignacio. Self-potential maps derived from these measurements are given in the geophysics report [9]. At Platanares, a prominent northwest-trending gravity ridge is approximately coincident with the mapped fracture zone in the Quebrada de Agua Caliente along which many of the hot springs discharge. A small gravity high along this ridge and south of the location of the first gradient corehole may result from an andesite intrusion or from the silicification of tuffs of the Padre Miguel Group. High contact resistance, local variations in soil properties, and temporal variations of hydrologic properties caused severe noise problems in the SP surveys. As a result we consider the results to be of questionable value. Additional boreholes were placed west of the Quebrada de Agua Caliente does suggest that the main up-flow of thermal waters may be on that side of the Quebrada. Gravity gradients on the San Ignacio maps correlate with faults on the geologic map [7] substantiating their importance in controlling permeability. The SP data from San Ignacio were of good quality and no major noise problems were encountered. Despite the high quality data only one anomaly appears on the San Ignacio map. The lateral extent of this east-west trending anomaly is small for a major geothermal feature and is more consistent with a small mineralized body.

Program funds were available for drilling two geothermal gradient holes approximately 500 meters deep. Each hole were drilled in Platanares. Because one of the major objectives was to obtain stratigraphic information, both holes were continuously cored. The other objectives were to measure the geothermal gradient and to obtain fluid samples from any aquifers encountered at depth. A detailed discussion of the gradient drilling is given by Goff et al. [10]. The site for the first corehole (PLTG-1) is on the west side of the village of Platanares. The site for the second corehole (PLTG-2) is on the east side of the Quebrada de Agua Caliente, a few hundred meters north of the village of Platanares. The site is located along the major northwest-trending fracture zone from which 95% of the hot springs issue. Drilling commenced on October 19, 1986 and was completed on January 21, 1987. Essentially no drilling was done in December because of the Christmas holidays in Honduras. Large fluid entries were encountered at 252 meters and between 625 and 640 meters. Several hot water and steam eruptions occurred during the coring operations but all were contained and coring continued to a final depth of 650.4 meters. Core recovery was greater than 98% despite the eruptions and occasionally intensely fractured rock. A flow rate of about 350 l/min was measured in the 525-540 meter zone. The geology consisted of mainly altered andesites to a depth of 653.7 meters where redbeds were encountered. A bottom-hole temperature of 160°C was measured but no well-defined gradient could be measured because of the hydrologic problems. The site for PLTG-2 is about 1 km south-southeast of PLTG-1 in a relatively unfaulted block away from the main hot spring area. Drilling commenced on January 22, 1987 and was completed on February 15, 1987 at a depth of 401 meters. No major fluid entries were encountered although there was a flow of 5-10 l/min up the annulus of the HQ rods left.
A PRELIMINARY CONCEPTUAL MODEL OF THE PLATANARES GEOTHERMAL SYSTEM

Based upon the results of prefeasibility investigations including gradient drilling, a preliminary conceptual model of the Platanares geothermal system has been developed. This system is very similar to the Basin and Range type geothermal systems of the western United States. The heat source is nonmagmatic; instead the water is heated during deep circulation along faults 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 system occur within a 3.2 km² area surrounding the northwest-trending Quebrada de 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 de Agua Caliente and several smaller east to northeast-trending faults. 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 at temperatures 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 at a depth of about 250 m may originate from leakage and convection from the deeper, higher temperature reservoir. Flow tests conducted on PLTG-1 indicate that this well taps 0.06 km³ of 160-165°C water within the shallow reservoir. Flow rates of up to 440 l/min were measured from the shallow reservoir.

FUTURE WORK AT THE PLATANARES GEOTHERMAL SITE

Several major activities remain to be completed before a final recommendations report is submitted to ENEE in January, 1988. Approximately two weeks will be spent in October mapping geologic structures at the Platanares site. Concurrently, the USGS will run AMT/MF surveys at the site. Results of these investigations will help determine the size and geometry of the geothermal system. A preliminary economic study will also be completed. If results continue to be favorable, ENEE, Los Alamos, and the USGS will prepare a proposal seeking funding for feasibility stage investigations at Platanares. These investigations would include testing of both reservoirs.

COUNTRY-WIDE GEOTHERMAL ASSESSMENT OF HONDURAS

Although much of the ENEE, Los Alamos and USGS work has, by necessity focused on the identification and initial characterization of the highest potential geothermal site, limited country-wide assessment work has been started. A catalog of all hot springs and thermal place names in Honduras [11] has been completed and published. New gravity anomaly maps of Honduras and adjacent countries will be used to examine relationships between major geologic structures and the locations of geothermal areas and hot springs. Analysis of fluid samples from hot and cold springs throughout Honduras will provide estimates of heat flow.

SUMMARY

Both country-wide and site-specific geothermal assessments have been in progress in Honduras for about two years. A combination of reconnaissance and detailed investigations have led to geothermal gradient drilling at the Platanares site in western Honduras. Three coreholes have been completed and the results to date are very encouraging.

REFERENCES


