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EXPLORATION GEOTHERMAL GRADIENT DRILLING, PLATANARES, HONDURAS, CENTRAL AMERICA

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ABSTRACT

This paper is a review and summary of the core drilling operations component of the Honduras Geothermal Resource Development Project at the Platanares geothermal prospect in Honduras, Central America. Three intermediate depth (428-679 m) coreholes are the first continuously cored geothermal exploration boreholes in Honduras. These coring operations are part of the Central America Energy Resource Project (CAERP) effort funded by the Agency for International Development (AID) and implemented by the Los Alamos National Laboratory (Los Alamos) in cooperation with the Empresa Nacional de Energia Electrica (ENEE) and the United States Geological Survey (USGS) [1]. This report emphasizes coring operations with reference to the stratigraphy, thermal gradient, and flow test data of the boreholes.

The primary objectives of this coring effort were (1) to obtain quantitative information on the temperature distribution as a function of depth, (2) to recover fluids associated with the geothermal reservoir, (3) to recover 75% or better core from the subsurface rock units, and (4) to drill into the subsurface rock as deeply as possible in order to get information on potential reservoir rocks, fracture density, permeabilities, and alteration histories of the rock units beneath the site. The three exploration coreholes drilled to depths of 650, 428 and 679 m, respectively, encountered several hot water entries. Coring operations and associated testing began in mid-October 1986 and were completed at the end of June 1987.

BACKGROUND

At the time of the initiation of the Honduras geothermal assessment in 1985, six sites were known that appeared to have geothermal potential (Fig 1). Reconnaissance geological and geochemical investigations were completed at these sites [2,3]. Probable reservoir temperatures calculated from geochemical geothermometers (Table 1) clearly indicated that the Platanares site had the highest predicted reservoir temperature (225-240°C). In addition, the area of surface geothermal manifestations is particularly large

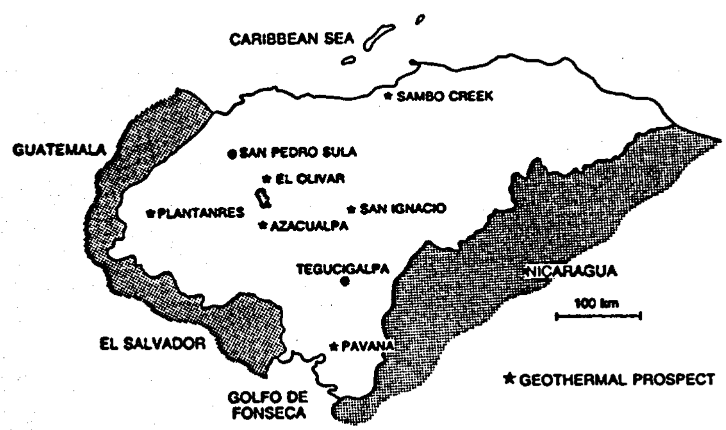

Fig. 1. Location map, Honduras geothermal prospects.

at Platanares, discharging 3500 ℓ/min unmixed reservoir water [3].

Detailed geologic mapping and additional geochemical sampling were then performed at four of the sites, including Platanares, while detailed gravity and self potential surveys were done only at the Platanares and San Ignacio sites due to funding limitations. On the basis of predicted reservoir temperature, discharge rate, and geology, Platanares was selected for gradient drilling as the site with the highest geothermal potential.

SITE DESCRIPTION

The Platanares geothermal prospect site is located in the Quebrada del Agua Caliente just east of the village of Platanares and about 16 km west of Santa Rosa de Copan. Platanares is reached by rough dirt road from the south through the town of La Union about 15 km away. The region around Platanares is mountainous and deeply dissected. Elevations of nearby ridges exceed 1400 m, whereas hot springs in the Quebrada are at an elevation of about 700 m.

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

Site	Silica			Na-K	Na-K-Ca				Gas	
	Quartz[a]	Quartz[b]	Chal.	(Fournier)	β=1/3	Mg-corr.[c]	Na-Li	^{18}O-SP$_4$[d]	D-P[e]	CO_2-CH_4[f]
Platanares	201	185	183	219	214	---	292	232	224	188
San Ignacio	178	167	158	200	197	---	176	218	192	219
Azacualpa	183	171	163	199	182	---	148	190	231	162
Pavana	151	144	126	152	140	---	83	196	93	144
Sambo Creek	154	147	130	160	151	---	94	162	152	80
El Olivar	142	136	115	197	182	103	139	170	108	207

[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).

Platanares lies in a tectonic zone of late Tertiary to Quaternary extension [4]. Many boiling springs are present in the area. These thermal manifestations are localized along faults that cut the entire bedrock section [4], and thus the general geothermal character is somewhat akin to a typical hydrothermal system of the Basin and Range province of the United States [5].

The oldest rocks in the Platanares area are highly deformed Paleozoic(?) metamorphic rocks that lie in fault contact with Cretaceous to Eocene redbeds and Tertiary volcanic rocks [4]. The age of the volcanic sequence (14 m.y.) (Duffield, person. comm.) indicates that these rocks are too old to serve as a heat source for the geothermal system.

The hydrogeochemical data indicate that the geothermal reservoir at Platanares equilibrated at temperatures of 220 to 240°C within the Cretaceous redbeds of the Valles de Angeles Group, which underly volcanics of the Tertiary Padre Miguel Group [3].

OBJECTIVES

During the spring and summer of 1986 planning and contract negotiations began for the initial geothermal gradient drilling at Platanares. Swissboring Overseas Ltd., Guatemala, was selected as the drilling contractor. The intent was to core as deeply as possible vertically with the hope of coring through the Padre Miguel Group into the Valle de Angeles Group, the suspected reservoir rocks.

The technical objectives of the coring effort were to:

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 in order to get information on potential reservoir rocks, fracture density, permeabilities, and alteration histories of the rock units beneath the site.

The site of the first borehole, PLTG-1, was locate along a main NW-trending fault and fracture system frc which 95% of the thermal springs at Platanares issu (Fig. 2). The location was chosen to encounter hc water at shallow depths. Major hot water eruptior were encountered at 252 m and from a zone between 62 and 640 m.

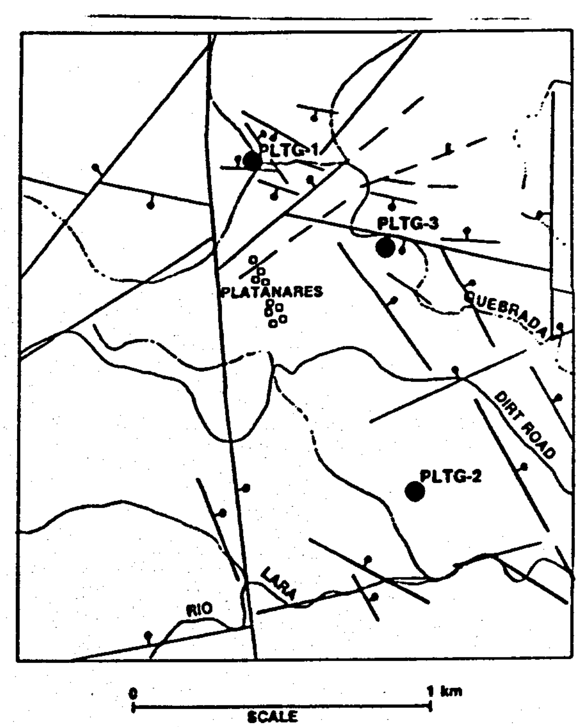

Fig. 2. Platanares geothermal site map (modified fro Heiken et al. [4]).

The second borehole, PLTG-2, was located 1 km SSE of PLTG-1 in a relatively unfaulted block, away from the main hot spring area (Fig. 2). The objective of PLTG-2 was to obtain a temperature gradient that was not influenced by convective upflow in the main spring area.

At the initiation of the coring phase of the Honduras geothermal project funds were available for approximately two 500 m boreholes. A cost-underrun on the coring of the first two boreholes and the encouraging results obtained provided the impetus to core drill a third borehole at Platanares with funding for this joint venture from Los Alamos, USAID-Honduras, and ENEE. The objective of the third borehole, PLTG-3 (Fig. 2), was to confirm the high temperatures and permeabilities observed in the first corehole [6,7,8].

SUMMARY OF CORING OPERATIONS

The core rig, a Longyear 44 powered by a 4-71 GM diesel engine, and having a 20 ft mast, was mobilized by Swissboring. Mobilization efforts required acquiring permits to cross international borders, road improvements, site preparation, and construction of camping and messing facilities, office space, field repair shop, and equipment and core storage areas. Figure 3 shows the site layout at Platanares.

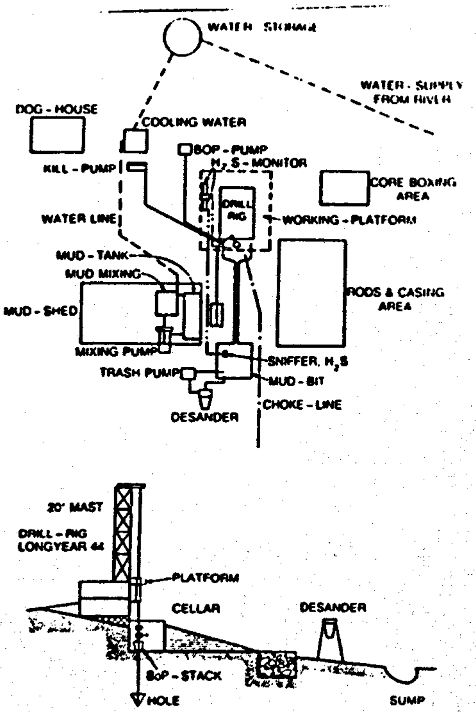

Fig. 3. Site layout, Platanares geothermal prospect.

<u>PLTG-1</u>

PLTG-1 was spudded on October 19, 1986. Surface conductor pipe was set to 10.2 m. PW casing, which served as a support for the BOP and wellhead stack was set to 70 m. The wellhead stack is shown in Figure 4. From 70 m, HQ size drill rods were used. On reaching 252 m, a major eruption of hot water occurred wedging the core barrel within the HQ rods. Attempts to control the eruption by killing the well with cold water were unsuccessful and all the HQ rods were tripped out of the hole under superheated, erupting conditions. Operations resumed with a closed circuit system using loading chambers and continuous cooling with fresh water during nondrilling periods. The core recovery system consisted of a shut-off valve in the drill string, loading chamber for the inner tube, and a receiving chamber for the overshot assembly and core barrel inner tube. The inner tube head contained a nonreturn valve as in the Longyear "Q" underground system to allow change of rods and core withdrawal. The core recovery operations through the receiving chamber were done by pumping cooling water through the HQ drill string to pressure up the system to unlatch the inner tube and to avoid uncontrolled rise of the core barrel up through the drill string. The loading of the core barrel inner tube was achieved by closing the system to equalize pressure. This system was used from 252 m to 588 m. Hot water entries occurred at various depths during the drilling but tight control on the system prevented additional eruptions. Lost circulation occurred between 525 to 563 m, where the Valle de Angeles was encountered [6].

Operations were shut down during December at a depth of 588 m. In mid-January an attempt was made to cement the HQ string up from 588 m to seal off the major fluid entry of 160°C water, which was dominating the temperature of the borehole and perturbing gradient measurements. The cementing job was successful in sealing off lost circulation zones near the bottom of the borehole. Another attempt to seal off the upper fluid entries by pumping cement down the annulus succeeded only for the upper zones (70-252 m). Drilling resumed with NQ rods with the goal of obtaining 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 [6].

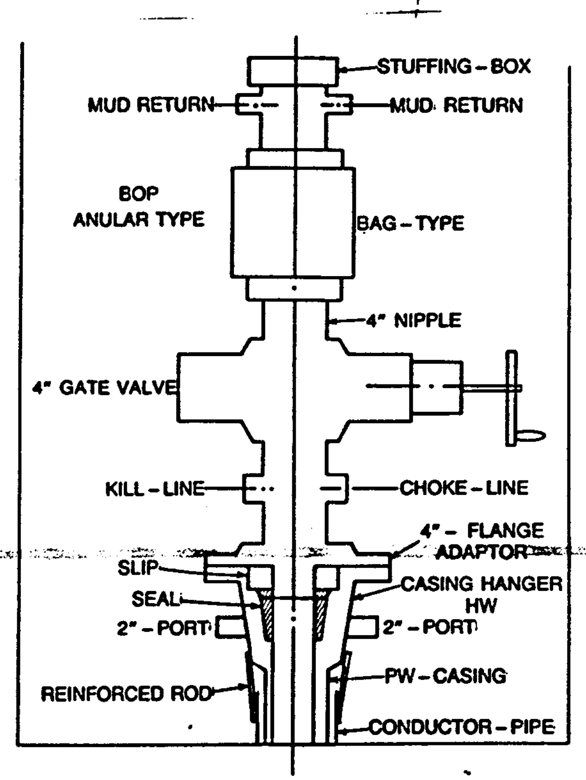

Fig. 4. Wellhead stack, Platanares coreholes.

The temperature of this fluid was 160°C and the flow rate about 90 gallons/min. The borehole was completed to a total depth of 650.4 m on January 21, 1987. Figure 5a presents the corehole configuration for PLTG-1, and Figure 5b the completion diagram. Coring operations are summarized in Figure 6. The target depth of 500 m was reached on Day 29 of operations. The average advance rate was 16.26 m/day for the 40 days of rig operations. Figure 7 provides a summary of significant rig activities by percentage of total rig operating time. Actual coring operations occupied 52.5% of the total time. A significant percentage of "other" time (13.4%) was spent developing the methodology for continuing the borehole during the eruption, which occurred when the hole reached a depth of 252 m.

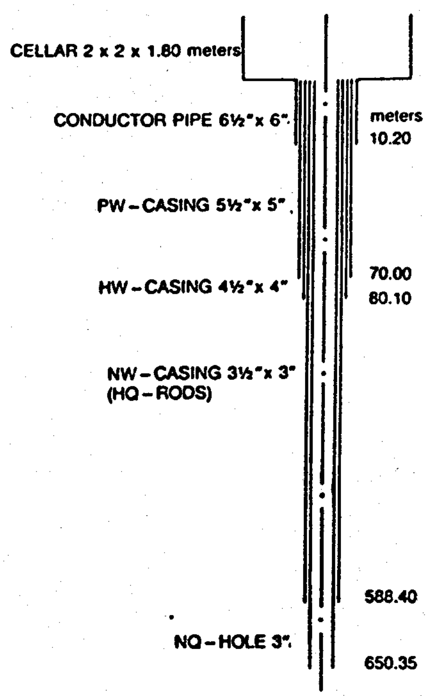

Fig. 5a. Actual (as built) borehole configuration, PLTG-1.

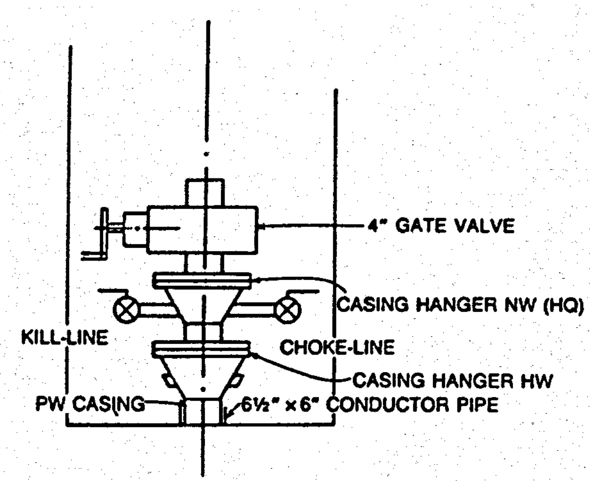

Fig. 5b. Wellhead completion, PLTG-1.

PLTG-2

The core rig was relocated to the PLTG 2 site on January 21, 1987 and spudded in PQ size on January 22, 1987. On reaching the depth of 77 m, the hole was reamed. PW casing was set, and the BOP installed. Coring continued rapidly in HQ to 397.7 m after penetrating a redbed unit at 311 m. On February 5, 1987, the core barrel threads stripped leaving the inner tube in the corehole. A fishing operation recovered the inner tube and drilling resumed for fifteen hours. On February 6, when drilling at a depth of 428.4 m, the core barrel threads again stripped and parted. The wireline broke near the surface and the overshot assembly sent down the hole to retrieve the inner barrel was lost. Although the next two days were spent fishing, the overshot and inner core barrel could not be recovered. On February 9 the decision was made to "kick around" the lost core barrel. While tripping in HQ rods to be used as casing for the reduction to NQ size rods a depth of only 424 m could be reached. Before grouting, the NW casing (HQ rods) was withdrawn to 394 m to allow sufficient interval for the "kick off" attempt. Three "kick off attempts failed due to caving and swelling clays. Various mud additives were tried without success. After the third attempt, the decision was made to stop drilling on February 16 [6].

The final corehole configuration as-built is shown in Figure 8 and the wellhead completion in Figure 9. The borehole was completed to 401 m on day 24 of rig operations. The average advance rate was 16.7 m/day for the 24 days of rig operations. Figure 10 presents the coring operations history for PLTG-2. The summary of significant rig activities by percentage of total rig operating time is shown in Figure 11. Coincidentally, the same percentage time (52.5%) was spent in coring PLTG-2 as PLTG-1.

PLTG-3

The success of the first two coreholes provided the impetus for a joint venture among Los Alamos, ENEE, and USAID Honduras to drill a third corehole, PLTG-3. 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. Drilling continued cautiously to 26.75 m when the decision was made to set the BOP to the PW casing. A 128°C temperature was measured at 25 m. Coring continued with HQ size rods and redbeds were encountered at a depth of 289 m. Coring continued smoothly although at times slowly due to shaley zones to 387.7 m. At 362.4 m a fault zone was drilled and andesite re-encountered. At 387.7 m a piece of metal was retrieved along with the core. Apparently a part of the HW casing had fallen to the bottom of the hole and was cut off by the bit. The decision was made to cement the HQ rods at this point. Some difficulties were encountered drilling out the HQ bit, but coring operations with NQ rods commenced on May 27 and continued in andesite to 590 m on June 1. Another hot water entry was encountered at 457 m.

At 590 m a core run was lost when the core barrel didn't latch in the inner tube. When attempting to redrill there was only a small piece of core in the inner tube and the decision was made to pull the rods, a difficult operation due to the flow of steam and hot water. After a bit change (the old bit cored over 250 m) coring continued to 635.7 m. The Valle de Angeles was encountered at 622 m and another major hot

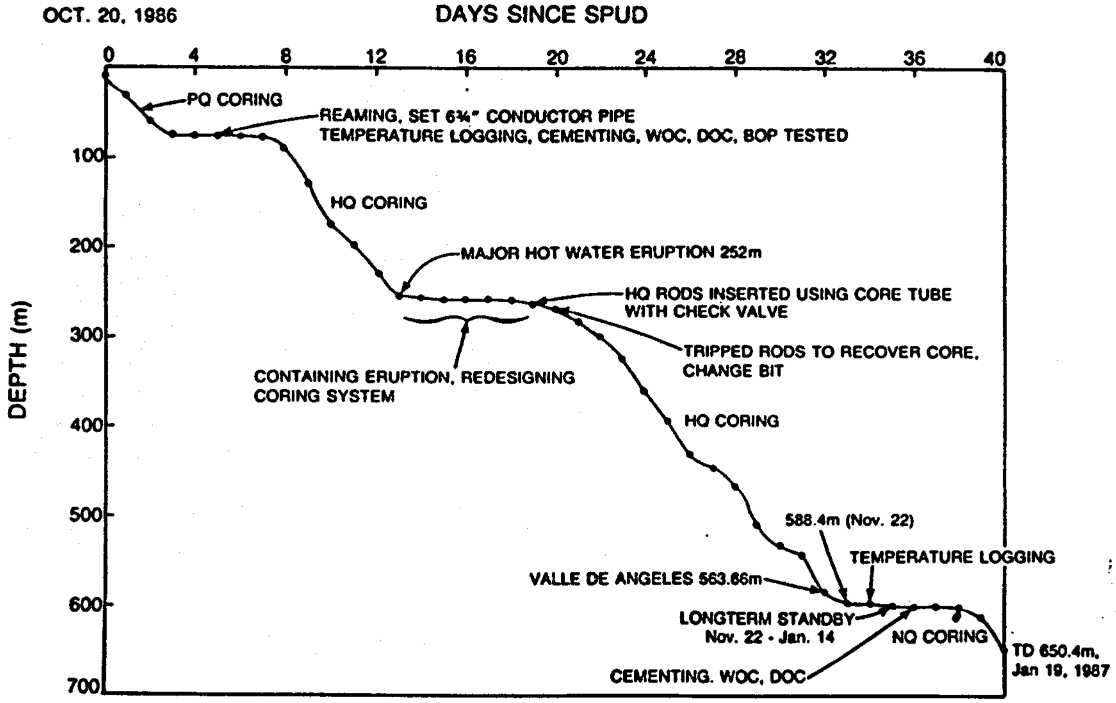

Fig. 6. Coring operations history, PLTG-1.

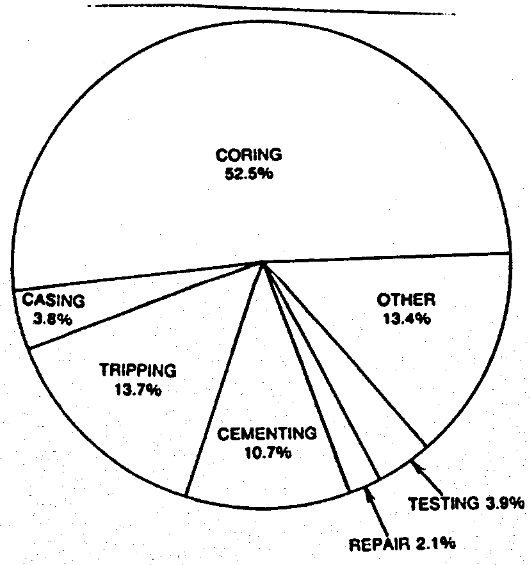

Fig. 7. Activities by percentage of total rig time, PLTG-1.

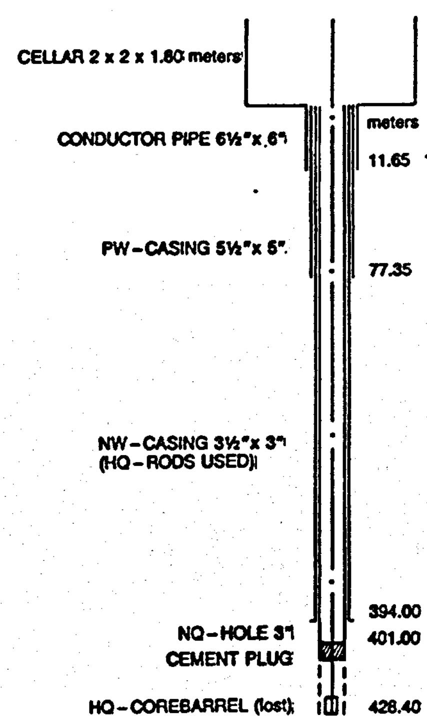

Fig. 8. Actual (as built) borehole configuration, PLTG-2.

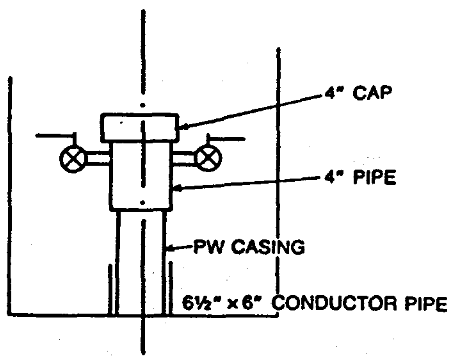

Fig. 9. Wellhead completion, PLTG-2.

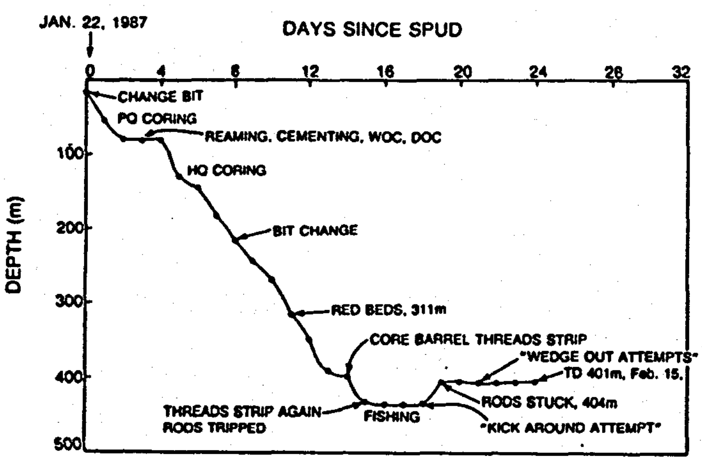

Fig. 10. Coring operations history, PLTG-2.

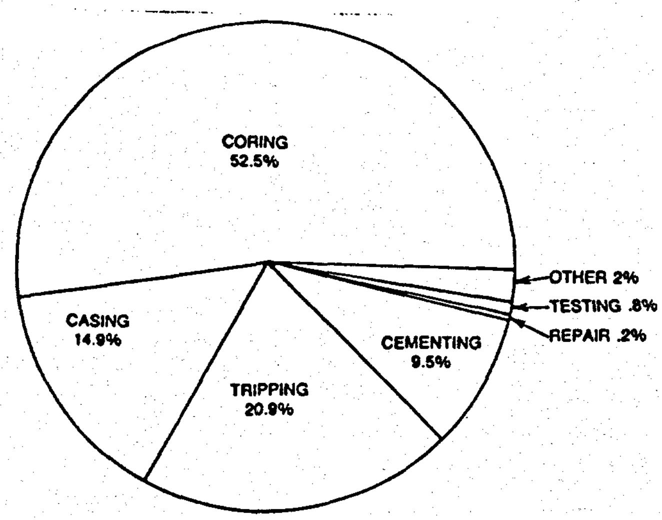

Fig. 11. Activities by percentage of total rig time, PLTG-2.

water entry at 625 m. The extremely abra conditions encountered in quartz pebble conglomer of the Valle de Angeles required four bit cha between 635.7 m and 679.0 m.

In attempting a temperature test with the Ku tool through the HQ rods it was discovered that rods were blocked at 289 m. It was concluded there is a hole in the casing (HQ rods) at this dep

On June 10 T.D. was reached at 679 m. temperature logs were run with the NQ rods in plε The NQ rods were pulled out of the hole on June 11 flow test equipment installed for the flow test operations [7]. Upon completion of flow tes activities (July 2) the NQ rods were replaced in bore hole as a liner. Figure 12 shows the borel configuration for PLTG-3 and Figure 13 the welll completion.

PLTG-3 was completed at 679 m on day 32 of operations with an average advance rate of 21.2 m day. The coring operations history for PLTG-3 is sl in Figure 14. Figure 15 presents the summary significant rig activities by percentage of total operating time.

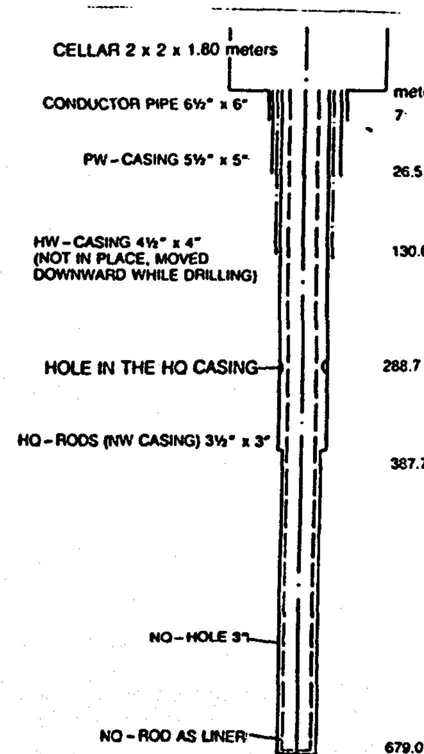

Fig. 12. Actual (as built) borehole configurati PLTG-3.

CORE RECOVERY

The amount and quality of the core recovered w consistently high throughout the entire operation. I initial core recovery occurred in PLTG-1 and -3 in t first 7.2 m and 6.8 m respectively of drilling in t fine sand and clay of the river deposits and in PLT(in the first 13.25 m of unconsolidated terrace gra material. Below the Quaternary gravel/volcanic conta core recovery averaged 98%. Core was curated on si by Los Alamos and ENEE geologists following procedur modified form those developed at Los Alamos [9].

PRELIMINARY RESULTS

Stratigraphy

The stratigraphy and correlations of the coreholes is shown in Figure 16. The boreholes penetrate thin Quaternary deposits and enter sequences of Miocene volcanic rocks. Cretaceous to Eocene red beds of the

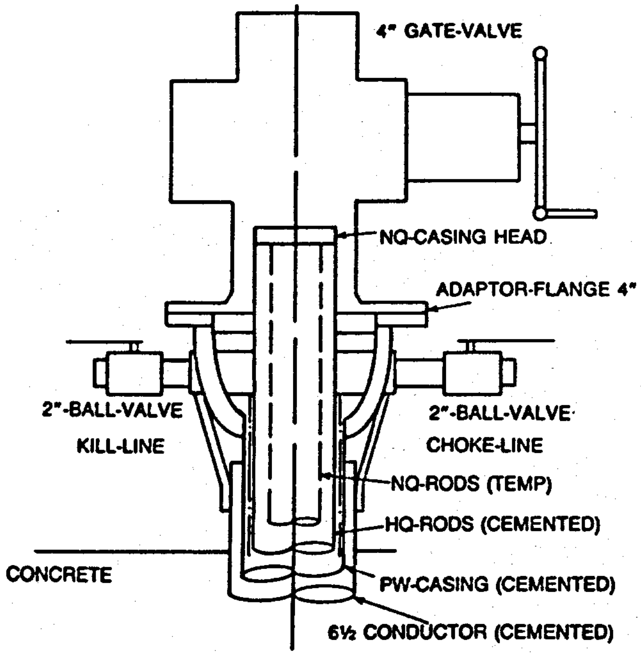

Fig. 13. Wellhead completion, PLTG-3.

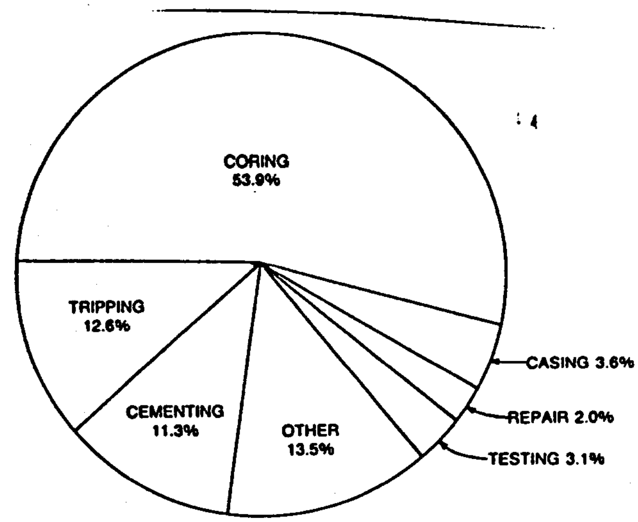

Fig. 15. Activities by percentage of total rig tim PLTG-3.

Valle de Angeles Group were intersected at 563 m PLTG-1 and 622 m depth in PLTG-3. These rocks consi of interbedded sandstones, conglomerates, siltstone and shales; this unit also occurs throughout centr Honduras. Rocks in PLTG-1 and -3 are faulte fractured, veined, and altered. Alteration and vei filling minerals include quartz, calcite, illit chlorite, pyrite, chalcopyrite, barite, stibnit fluorite, marcasite, and laumontite. Alteration PLTG-2 is less intense although cores are local faulted, fractured, and veined [8].

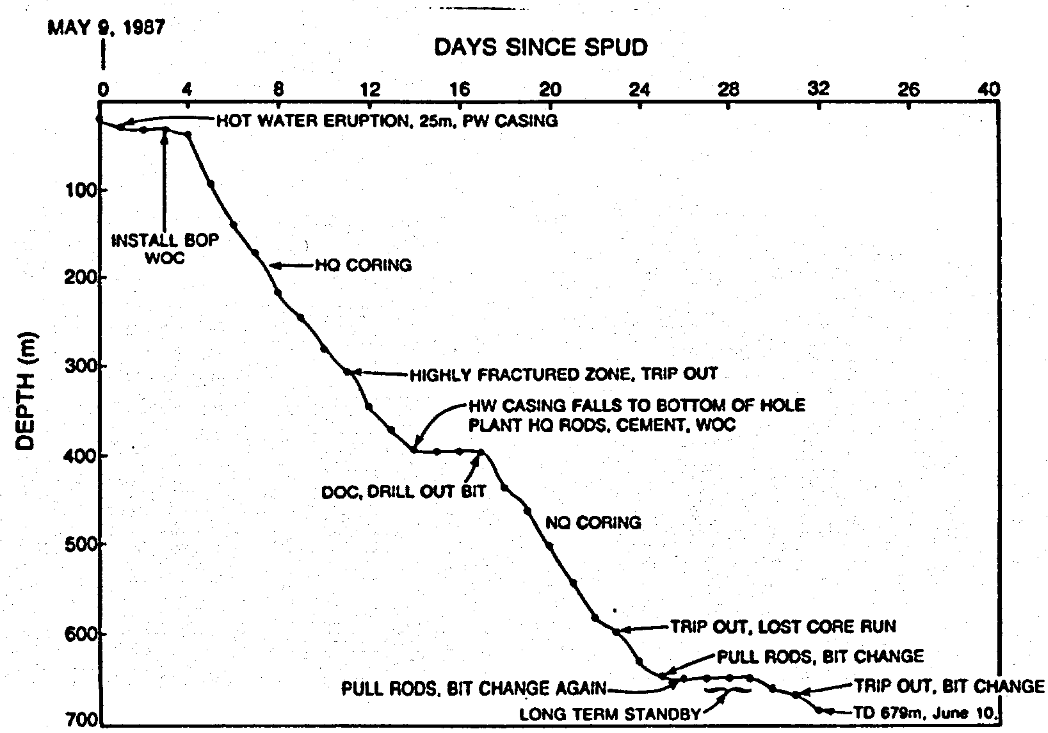

Fig. 14. Coring operations history, PLTG-3.

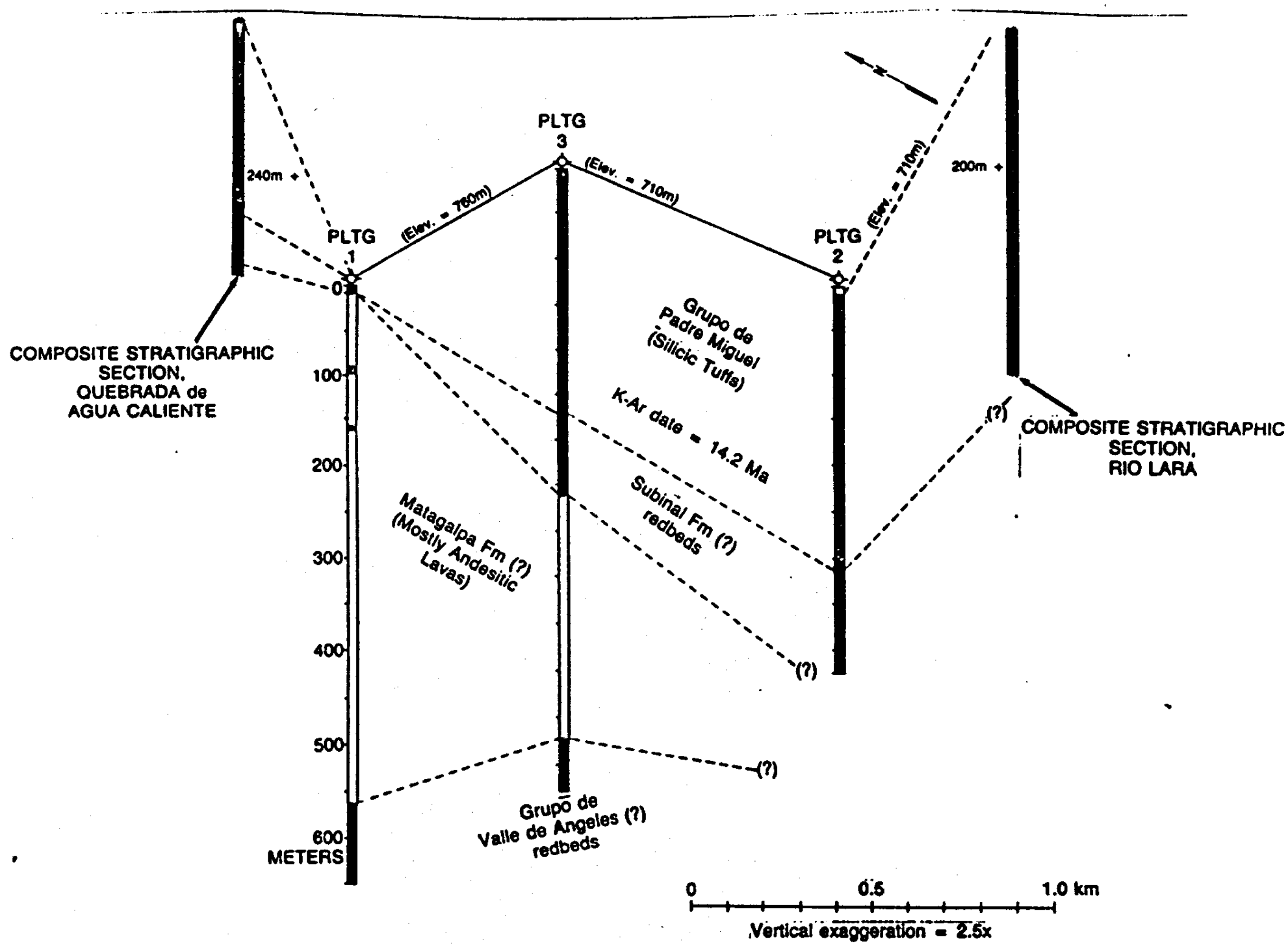

Fig. 16. Correlations, Platanares geothermal site (from Heiken et al. [8]).

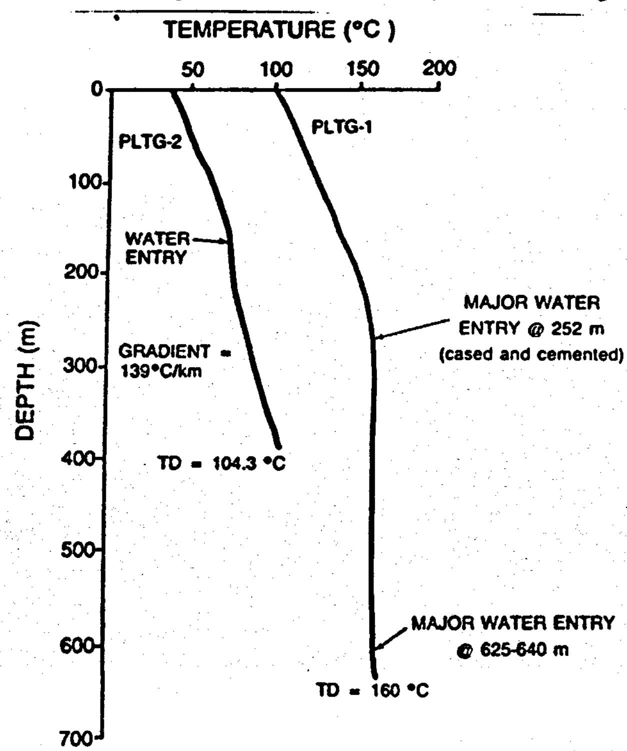

Fig. 17. Temperature vs depth profiles of PLTG-1 and PLTG-2 coreholes (from Goff et al. [7]).

Temperature Gradients

Plots of temperature versus depth for PLTG-1 a PLTG-2 are shown in Figure 17. PLTG-1 produces wat from an intensely fractured zone of green altere metaconglomerate at 625 to 640 m depth. Temperatur in PLTG-1 climb rapidly to about 152°C at 252 m (ne another large water entry) and then the gradie becomes essentially isothermal at 160°C to the bott of the well. Temperatures in the bottom of the we are dominated by the large water entry at 625 to 640

PLTG-2 produces very small quantities of wat (5-10 ℓ/m) from the annulus of the HQ rods. T maximum temperature of PLTG-2 is 104.5°C at 401 m. T log shows two zones of high gradients; an upper zo where the gradient is about 239°C/km and a lower zo where the gradient is about 139°C/km. Although t lower gradient is linear and appears conductive, value of 139°C/km is too high to be caused solely conductive heat flow [7]. Estimated depth to t source reservoir of the Platanares system (220 240°C) is about 1.2 to 1.5 km based on downwa continuation of the 139°C/km gradient in PLTG-2.

A hot water eruption occurred at only 25 m PLTG-3. Other major hot water entries were encounter at 458 m and a zone from 621 m to 635 m. PLTG-3 producing water at the rate of 550 liters a minute fr numerous water entries. Bottom hole temperature June 11, 1987 was 165°C.

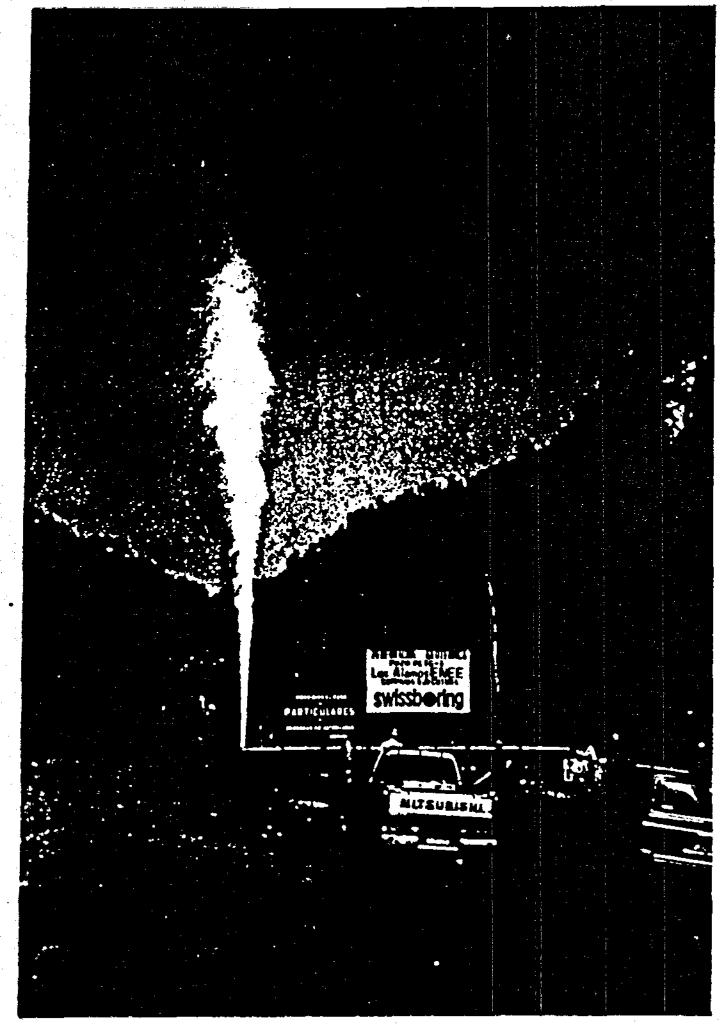

Fig. 18. Photograph of PLTG-1 erupting flashed reservoir water and steam into the sky through a 4-ii ball valve.

FLOW TESTING PLTG-1 AND PLTG-3

During late February and early March and then again in June of 1987 Los Alamos, ENEE, and USGS staff were on site at Platanares to collect fluid samples and perform flow tests on PLTG-1 and PLTG-3. Figure 18 is a photograph of PLTG-1 erupting flashed reservoir wat and steam through a 4-inch ball valve. Note the 3-ir flow line and flow tank used for the flow tests.

The 8-day flow test [7] of PLTG-1 showed a gradu decrease in flow rate until about 100 hours and then sudden decrease in flow rate until about 190 hour Dismantling the surface flow pipes and valves aft this test indicated aragonite scale lining the wellhe area of the flow equipment. A similar test perform on PLTG-3 in June (F. Goff, personal communication) d not produce scaling of aragonite in the well bore aft a few days of flow. It is believed that a modificati in the wellhead completion (Fig. 13) prevented t scaling problem in PLTG-3.

Although it must be pointed out that PLTG-1 a PLTG-3 are slim exploration coreholes, not intended be production or test wells, estimates were made of t maximum thermal power of PLTG-1 and PLTG-3. The max mum thermal power produced by PLTG-1 is approximate 3 MW thermal and for PLTG-3 4.4 MW thermal. Flow te data are summarized in Table 2.

SUMMARY AND CONCLUSIONS

The first geothermal gradient coreholes in Hondur have been successfully completed. Core recovery fr the three boreholes has exceeded 98% and the recover samples have been used to determine the depth to t top of the potential geothermal reservoir rocks, t stratigraphy, and the nature of permeability a alteration at the Platanares site. Temperatu measurements have been made and fluid samples collect for chemical analysis. Although these boreholes a slim exploration coreholes not intended to production or test wells, flow tests were performed a estimates were made of the maximum thermal power PLTG-1 and PLTG-3.

These very encouraging results indicate th feasibility stage assessment should be initiated at t Platanares geothermal site, Honduras. There is definite shallow reservoir of about 160°C a considering the temperature, flow rates, permeabilit and probable fluid volumes, development of the shall reservoir using binary cycle generators appea feasible. The apparent temperature of 225-240°C of t deeper reservoir makes it a high potential target f future investigation.

To best meet ENEE's need for increased generati capacity by 1992-93, both the shallow and de geothermal reservoirs at Platanares require furth assessment and testing [10].

TABLE 2. Summary of Flow Test Data from PLTG-1 and PLTG-3 (from Goff et al. [7]).

	PLTG-1	PLTG-3
Date	Feb. 1987	June 1987
Max. 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
Max. Temperature after Shut-in	145°C	158°C
Power Output @ Max. 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.)

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