WELL ZD-1, THE FIRST PRODUCTION WELL IN GRANODIORITE BASEMENT AT THE ZUNIL I FIELD, GUATEMALA

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SUMMARY - Well ZD-1, the first of a series of three development wells planned for the Zunil I field, was drilled and completed to a depth of 1516 m. The well successfully met its objective encountering a zone of high temperature and high permeability near 1,466 m-1,475 m depth, within crystalline basement rocks. ZD-1 was drilled vertically to a depth of 730 m, then it was directionally drilled towards its target, south of the wellhead location. The well reached a maximum drift angle of 13 to 15 degrees, with a true vertical depth of 1,497 m, and the bottomhole location is 158 m south and 23 m east of the wellhead. high permeability ~one was found in the granodiorite, beginning at 1466 m. This is expected to be the production zone for ZD-1. The injectivity index is 19 cu m/hr/ksc. From the vertical discharge, an initial productivity of about 14 MW was estimated.

INTRODUCTION

Drillhole, ZD-1, the first of the three development directional wells at the Zunil field, was completed and successfully tested by the Instituto Nacional de Electrificacion -INDE- in April 1991, marking a successful start for the near future program of geothermal development in Guatemala. Results of ZD-1 are encouraging and widen the expectation of surpassing the current program's objective of developing and installing a 15 MWe power plant, which will provide a significant portion of power requirements for western Guatemala.

During the last fifteen years, the Republic of Guatemala, through the Unidad de Desarrollo Geotermico of the Instituto Nacional de Electrificacion (INDE), has been carrying out continuous geoscientific studies of its territory, being that large portion crossed by a broad volcanic chain which has shown constant activity from Tertiary times to the present. The objective of these studies is to locate and evaluate areas with geothermal resources. One of these areas is the Zunil geothermal area Within this area, the portion known as Zunil I is now in the developing and production drilling stage. The Zunil geothermal area is located approximately 200 km west of Guatemala City, near the village of Zunil (fig. 1).

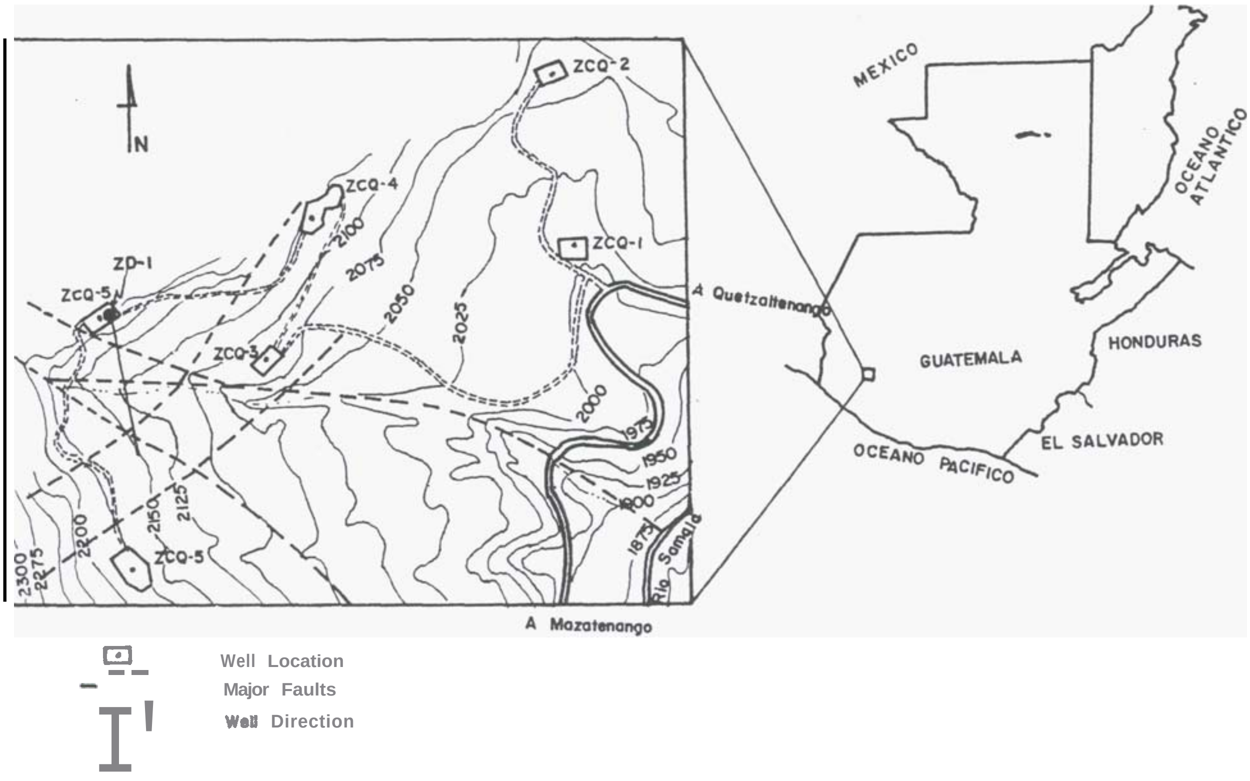

Fig. 1. Location of ZD-1.

The area is formed by a Cretaceous granitic basement covered by Tertiary and Quaternary lavas and pyroclastic deposits, The tectonic influence is apparent in the way of a series of alternating grabens and horsts with a general tendency to deepen to the west. In addition, there are many circular features and curved faults in the Zunil area (Tobias and Quiesa, 1 98 1, CyM, 1989). It is thought that these features are the result of caldera collapses and large ancient landslides.

The Zunil geothermal area is located mainly in the southern half of the Quetzaltenangocaldera. In this area, thick piles of lava flows and pyroclastic rocks of Pleistocene age have accumulated. There are also historic and active volcanoes located along NE and WNW trending faults.

After several years of geoscientific studies, a 4 sq km area was selected in the Zunil geothermal area. This area was named Zunil 1.

From March 1980 to October 1981, six deep exploratory wells (ZCQ wells) were drilled in an area of 1 sq km with an average depth of 1,000 m; four of these wells are productive ones, with temperatures ranging between 270 and 290°C.

The production zone of these wells is located at the contact of the Tertiary volcanic products and the granitic basement.
According to the production tests, the steam flow separated at 8 bars is between 5 and 10 kg/s, for the four productive wells; they are able to produce about 11.5 MWe. but also from the tests it was found that a significant pressure drop, of the order of tenths of bars, occurs at the depth when the wells are flowing. This is due to the low permeability shown by the formations, especially in the granitic basement, with conductivity values between Kh=5E-13 and 5E-12 sq m. This low permeability is also noted in the type of hydrothermal alteration determined in cores and cuttings from the wells.

The geologic, hydraulic and thermodynamic parameters obtained from the exploratory wells were used in the mathematical modelling of the field, which determined a potential of 15 MWe for the Zunil I area, that can be exploited during the economic life of the geothermal plant, assumed to be 20 years.

In order to develop the field and keep the production stable during the economic life of the plant without a significant pressure drop and, based on the geoscientific studies performed by MKF-CyM-INDE in 1988-1989 (including neotectonics, geochemistry, geology and geophysics), a production drilling programme was established. This program was intended to reach the main upflow zones of the field. These zones correspond to major fractures and faults of the granitic basement and are mainly concentrated in the west part of the field. Due to the steep topography of the area and the structure of the basement, it was decided to drill directionally, in order to intersect as many fractures and faults as possible, using existing pads.

GEOLOGICAL SETTING

As mentioned earlier, the Zunil area is located mainly in the southern half area of the Quetzaltenango Caldera. In this area there are three predominant fault systems: (1) NE, (2) E W and (3) NW and/or WNW trends.

The NE trending faults are concentrated along the Samala River. and cut the middle Pleistocene volcanic rocks. The NE trending fault is more conspicuous than the other two systems and belongs to the Zunil fault zone. The Zunil geothermal area has been affected by the movement of these faults. In fact, the granitic basement is faulted down toward the west along the NE trending faults, forming a series of alternating horsts and grabens.
The NW-WNW trend is closely related to tectonic movement along the Guatemalan volcanic chain.
The E-W trend is the result of the stress field generated by the other two movements.

In the Zunil region, volcanic activity began in the Miocene and continued throughout the Quaternary. The Tertiary lavas were extruded from fissure eruptions and formed a large plateau. The Guatemalan volcanic chain represents a large negative gravity anomaly, where huge calderas, such as the Quetzaltenango caldera, are located. There is a thick pile of ash-flow tuff and tuffaceous sediments in the depression zone. The volcanic cones were constructed during the Quaternary.

There are a lot of thermal manifestations, including hot springs, fumaroles and steam vents. Most of the thermal manifestations are concentrated along the Samala River, where all the chloride type hot springs discharge. This means that these hot springs are part of an outflow structure.

Fluid and gas geothermometry has shown that the temperatures in the reservoir are of the order of 280 - 300 C.

DRILLING OF ZD-1

Well ZD-1 was planned as a 2000 m production well to be deviated to the southwest, with a target direction of S08W and a drift angle of 13 degrees, where productive fractures and high temperatures were anticipated. Even though one of the proposed drilling targets was not reached, the well encountered fractured zones of high temperature-permeability production

ZD-1 first penetrated a thin sequence of alluvial deposits and andesitic-dacitic volcanic breccias, with the first lost of circulation at 15 - 17 m. Below that, a thick sequence of pyroclastic rocks interlayer with andesitic lava flows was drilled between 17 and about 966 m, where the contact with the basement was hit.

The pyroclastic rocks include mainly crystal tuffs, lithic tuffs and tuff-breccias. The crystal tuffs are composed by crystals of quartz, hornblende and biotite in a strong to moderate silicified ash matrix, while the lithic tuffs are composed by lithic clasts of andesitic-dacitic lavas and pumice in a silicified ash matrix.

This sequence seems to be rather impermeable down to 671 m where the next circulation loss occurred. Blind drilling took place between 671 and 700 m. At this depth a tuff breccia was found; soft, quite fractured and permeable, the hydrothermal alteration increased significantly, especially in the matrix which was almost fully replaced by clays (chlorite/smectite).

Underlying the tuff breccia was drilled a 50 m thick andesitic lava flow, hard, porphyritic with phenocrysts of plagioclase, veined with calcite+quartz+clays filling the veins.

Directly below a lithic tuff was penetrated; hard with glass shards and andesitic lithic clasts The first appearance of epidote as hydrothermal mineral was in this sequence.

The next loss of circulation was at 812 m depth, forcing blind drilling between 812 and 850 m.

The contact between the volcaniclastic products and the basement was at 966 m depth. The basement rock has been classified as granodiorite. The granodiorite is a hard, light gray to gray green, medium grained plutonic rock composed of feldspars, quartz, abundant biotite and minor fine grained magnetite. The roof of the granodiorite is extensively veined and altered, with veins of illite and hematite, quartz, calcite and chlorite. The deeper granodiorite is fresh, except in those parts where faults or fracture zones were identified, i. e. at 1250 m, where small to moderate loss of circulation occurred, with moderate intensity hydrothermal alteration. Finally, at the 1466-1475 m interval, where the total lost of circulation occurred, moderate hydrothermal alteration was found also.

After the total loss of circulation occurred at 1,466-1,475 m, the drilling of the well was done blind, finishing at 1,516 m. (Total depth from KB).

Hydrothermal alteration

The hydrothermal assemblages found in the cuttings of the well can be classified as either argillic of propylitic. The upper 100 m are clearly dominated by acid products (i.e. caused by acid sulphate waters) such as kaolin, tridymite and silica residue. Argillically altered rocks are found between 200 m and 300 m. These rocks have been variably altered to mixtures of smectite, interlayered illite-smectite and chlorite-smectite, quartz and calcite. This part is typical of alteration by neutral to slightly alkaline pH waters at moderate temperatures (180-200°C).

Within the propylitic zone, the rocks have been altered to illite, quartz, calcite, chlorite, epidote, pyrite and hematite, with epidote occurring below 680 m. Typical alteration of neutral pH waters at high temperature (250-300°C). fig. 2

Well casing

The final well casing and liner program for the ZD- 1 well was:

- 20 inch casing @ 44.5 m
- 13-3/8 inch casing @ 298 m
- 9-5/8 inch casing @ 64- m

Temperature-pressure and injection tests were performed by INDE on open hole, to determine the location of permeable zones and estimate the overall injectivity index of the well. Following the injection tests, a seven inch liner was run (blank liner to 1100 m and slotted liner to 1509 m), completion tests were performed, and the rig was released on May 1991 to prepare the wellsite for the ZD-2 well. (fig. 3)

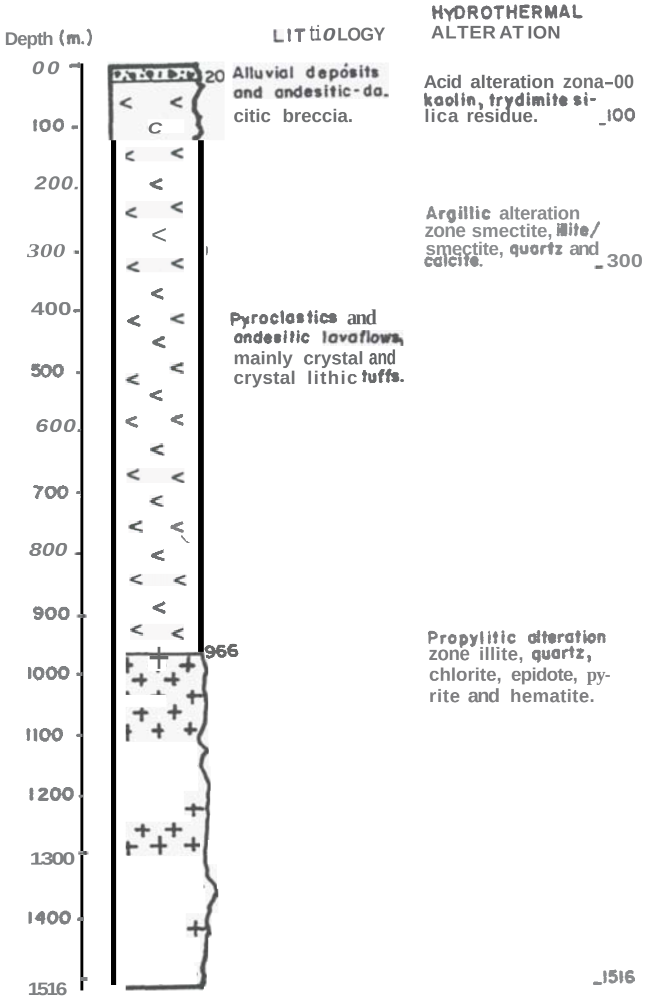

Fig. 2. ZD-1 stratigraphic column.

Directional Drilling

The well ZD-1 was planned to be deviated to the southwest, with a target direction of S08W and a drift angle of 13 degrees.

The KOP (kick off point) for the directional drilling was 730 m with a build-up angle of 2 degrees/30 m.

Because of the blind drilling, due to a loss of circulation at the 812-850 meters depth interval, the direction of the well turned to the west to S24W. When the circulation was resumed, the direction was corrected with the mud motor.

The direction of the well was difficult to control, mainly because of the strong drifting eastwards, due to the structure of the basement, and also because the high temperatures below 1389 m, which made it impossible to use the mud motor.

Another interval of blind drilling occurred at 1466 to 1475 m and, because of the added risk of losing the drillstring while drilling blind, the monel collar was not run while drilling the final interval. Therefore no directional surveys were run between 1452 and 1516 m. The bottomhole location has been projected based on the last survey at 1452 m (S28E with a drift angle of 13°45'). The projected location is 158 m south and 23 m east of the wellhead, about 30 m east of the original target; and the total vertical depth of the well is estimated in 1497 m.

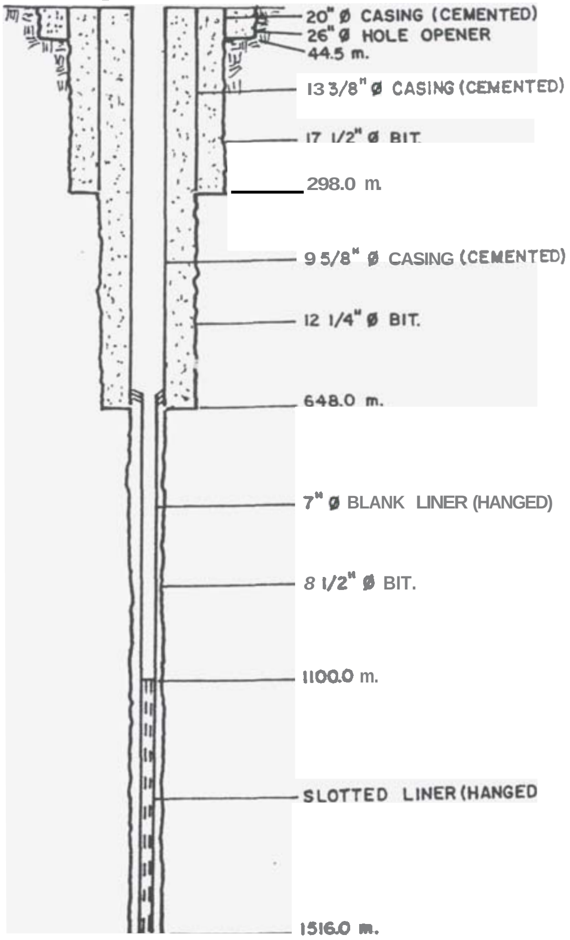

Fig. 3. Casing diagram.

DRILLING RESULTS

Temperature

Previous results from the ZCQ wells indicate that a heat-up period of weeks to months after completion is necessary for wells in the Zunil I field to fully stabilize. The surveys conducted during the post drilling heat-up period in ZD-1 reflect and confirm this pattern of behaviour.

From the temperature surveys we can conclude that a steady heat-up occurred since the time of well completion in mid April. It appears that by mid June the downhole temperatures had stabilized over most of the wellbore. Heat-up has been slower in the bottom part of the well, due to cooling by the injection in the permeable zone near 1475 m. At the time of the latest surveys this zone still had not fully heated. We expect that the temperature in this zone will be approximately equal to the temperature at 1450 m (about 295°C) when it recovers completely (fig 4).

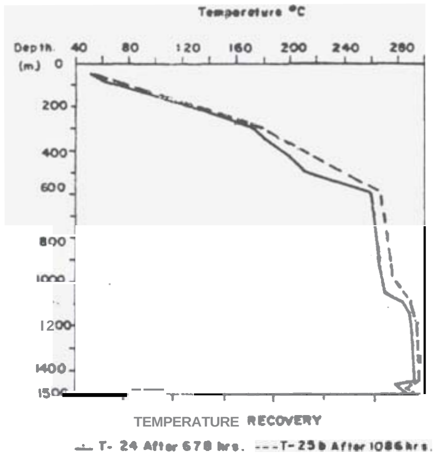

Fig. 4. Temperature log after injection test.

Permeability

Information about the location and magnitude of permeable zones in ZD-1 is available from circulation losses during drilling, injectivity tests carried out during drilling and at the time of well completion, results of downhole temperature and pressure surveys and hydrothermal alteration and mineralization.

These data indicate the presence of several zones of permeability at different depths, these zones are

1.- A major permeable zone between 1 ,466 m and 1,475 m. This is the zone where the greatest permeability was encountered, and it is the only permeable zone within the predicted target interval for ZD-1 (11 00-1516 m, where slotted liner has been installed). It is expected to be the main production zone of the well.

2.- A highly permeable zone near 671 m. This zone is below the production casing *shoe*, but it was cemented to facilitate further drilling. Blank liner has been installed in this interval.

3.- Scattered minor permeable zones between 671 and 1000 m.

The permeable zone near 1,475 m caused a total lost of circulation, and this was never restored.

The behaviour of this zone indicates that it is probably a major fracture zone or a set of fractures within the granodiorite basement. The temperature surveys indicate that the zone was cooled by the injection of water and mud, and has heated slowly, confirming the high permeability of the zone. Injectivity tests indicated an injectivity index of approximately 19 cubic m/hr/ksc, which is larger than the injectivity of any of the ZCQ wells.

Interestingly, the hydrothermal alteration observed in cuttings recovered from the zone right above the area of total loss circulation is not unusually intense, and is distinctly less intense than the alteration observed in several zones where no permeability was encountered (such as 1435-1440 m). Therefore the results from ZD-1 suggest that hydrothermal alteration may not necessarily be a guide to permeability within the basement rock.

VERTICAL DISCHARGE

After a 70 day heat-up period following the well completion, a 24 hour vertical discharge of ZD- 1 was conducted in July 1991, to clean up the wellbore and demonstrate commercial viability. Flow was initiated without any compressing the well, and continued uninterrupted for 24 hours.

Preliminary calculations of mass flow and production based on measured lip pressures indicated a flow rate of approximately 391 tons per hour through a 9-5/8 inch discharge tube, and by using and efficiency of 10% to convert thermal energy into electricity, we can estimate a well production of about 14 MWe (Cuevas, pers. comm.). Even though the flow rate increased slightly throughout the test, this was too short in time to give accurate data about the flow rate and electricity production. We have to wait for a long term production test with horizontal discharge. It is expected that ZD- 1 will show a stabilized long term capacity in the range of 8 to 10 MW.

CONCLUSIONS

1- Well ZD-1 successfully met its objective of encountering a ~one of high temperature and commercial permeability within granodiorite basement rocks of the Zunil I field.

2.-The well is expected to produce from a single zone of fracturing that begins near 1,466 m depth ~KB) and has a maximum vertical thickness of about 40 m. This is the only significant permeable zone within the interval completed with slotted 7 inch liner.

3.- Injectivity testing indicates that the injectivity index of ZD-1 is higher than that of any of the ZCQ wells.

4.- The temperature at the production zone is about *295 C.* This is well below the boiling point at this depth, and so indicates that the the well will produce single phase fluid from the reservoir.

5.-ZD-1 encountered the contact between &he volcanic sequence and the granodiorite at about 966 m. The granodiorite is lithologically monotonous from the contact to bottomhole, with variations only in grain size, texture and mafic mineral content.

6.- Rock alteration is generally more intense at the base of the volcanics and at the top of the granodiorite than within the rest of the granodiorite interval. There are scattered alteration zones of relatively intense alteration within the granodiorite, but these do not correspond to permeable zones, and the rock st the production zone is not altered more intensely than in adjacent intervals.

7.- Difficulties in achieving and maintaining hole direction occurred in the deviated portion of the well (below 730 m). These difficulties resulted from problems with drilling equipment and the abrasive nature of the granodiorite that contributed to wear out downhole tools, aggravating unwanted deviations.

8.-Evidence from drilling operations testing and downhole surveys indicates that well ZD- 1 is currently without damage and in good condition, suitable for testing and production.

9.- The vertical discharge test of ZD- 1, indicates that the well has an initial productivity of about 14 MW. It is expected that ZD- 1 will show a stabilized long term capacity in the range of 8 to 10 MW.

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