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Reservoir Assessment of Zunil I and II Geothermal Fields, Guatemala

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ABSTRACT

A conceptual model for Zunil I and II is presented from careful analysis of reservoir temperatures and initial pressures. The Zunil I reservoir is divided into an upper and lower reservoir by a lithological contact between a granitic formation and overlying volcanic rocks. Wells producing from the upper reservoir yield less total output while wells that produce from deeper reservoir have higher total outputs. There appears to be a main upflow in the western part of Zunil I at the intersection of northeast and northwest regional fault trends. A second upflow may be present near the eastern edge of Zunil I, possibly connected as a line source along a northeast trending fault to the main upflow in the western area. Pressure potentials are highest in the west, suggesting fluid upflow, with outflows to the northeast and east. The Zunil II area shows that temperatures are overall higher at shallower depths with a source upflow possibly located in the southeast area. Temperature and pressure distributions suggest that fluids are flow to the northwest. A volumetric assessment of the Zunil II reserve shows that there is a potential for 35 MWe for the next 35 years.

1. INTRODUCTION

The Zunil geothermal area is located 220 km west of the Guatemala City (Figure. 1). The Zunil geothermal area is divided into Zunil I field and Zunil II field. Exploration of Zunil began as early as 1970 by INDE, the national utility company. In 1981, it was decided to make a national inventory of all geothermal resources of Guatemala to understand and define the most promising areas for exploitation. Pre-feasibility studies were carried out with funds from INDE and a donation from the Latin American Energy Organization (OLADE and BRMG, 1982). The study classified seven areas, of them Zunil I and II were found to be among the most promising and were given priority. Zunil I has been under exploitation since 1999, when Ormat Inc. commissioned a binary geothermal power plant with an installed capacity of 24 MWe.

Between 1980 and 1981 INDE drilled 6 production wells in Zunil I to determine the geothermal potential of the Zunil I reservoir. The deepest of these wells, ZCQ-6 was drilled to 1142 m. It was estimated that Zunil I could produce enough steam to sustain 24 MWe production for 25 years (Palma-A. and Garcia, 1995). Drilling had confirmed the existence of a single phase (270-290°C) reservoir below 1000 m depth. Additional wells were needed to increase total production. From 1991-2004, INDE drilled 5 new wells in Zunil I and 2 new exploration well in Zunil II. The deepest well, ZD-3 was drilled to 2370 m. Currently, of the 11 production wells drilled in Zunil I, 6 wells are used for production and 2 for reinjection.

Zunil II is located east of Zunil I across Rio Samala (See Figure 1). Between 1989 and 1992, INDE carried out extensive geoscientific studies in Zunil II. Preliminary estimates based on pre-feasibility studies estimated Zunil II with a potential of 50 MWe for 25 years of utilization (West Japan Engineering Consultants et al., 1991). Two slim holes and one production well were drilled that confirmed the existence of a deep reservoir residing below a zone of supersaturated steam (West Japan Engineering Consultants et al., 1995). In 2003 INDE drilled a production diameter well with a total depth of 1923 m in depth. The well reached a maximum temperature of 240ªC. During the drilling no significant circulation losses were observed and numerous attempts to stimulate the well were unsuccessful. Although the well did not have a good connection with the surrounding reservoir, temperature and pressure logs did confirm reservoir conditions. INDE has plans to for a long term stimulation of the well by diverting a portion of the waste brine fluid from the power plant and reinjecting as much as possible into the well.

This paper presents a reservoir assessment study for the Zunil I and II geothermal fields. A revised conceptual model is presented that includes both Zunil I and II. Finally, a volumetric assessment based on temperature distributions of the Zunil II geothermal field is carried out using Monte-Carlo simulation in order to estimate the reserve potential.

2. DOWNHOLE TEMPERATURE AND PRESSURE

2.1 Zunil I wells

Reservoir temperatures and initial pressures for Zunil I are shown in Figure 2 and 3. The upper and lower reservoir boundary is at 1100 m a.s.l. Temperatures in the lower reservoir are close to or near 300°C while the upper reservoir has temperatures at BPW. Initial pressures vary a great deal in Zunil I and suggest heterogeneity in the reservoir. Generally, lower pressures are seen in wells that produce from the shallow reservoir. Low permeability of these wells causes flashing in formation and a high pressure drawdown and hence these wells are less productive tend least productive. The highest reservoir pressures are measured in wells ZD-1 and 2. These deeper wells show less pressure drawdown during discharge at the feedzones and have higher permeability. Table 1 shows well characteristics of flowrate conditions for wells in Zunil I.

2.2 Zunil II wells

Reservoir temperatures and initial pressures for Zunil II are shown in Figures 4 and 5. Temperatures measured in the well are close to saturation for wells Z-19, Z-20, and Z-21A while well ZII-1 has lower temperature. In the eastern part of Zunil II, temperatures increase and may reach 300°C at depths were a liquid reservoir may reside. Depressed water levels shallow wells from accumulated steam and gas may be the reason for the differences in the estimated boiling point with depth (BPD) profiles. Well ZII-1 did not tap into the Zunil II reservoir but the temperature profile may indicate a boundary condition to the west. Initial pressures were estimated to be hydrostatic down to the well bottom.

3. A CONCEPTUAL MODEL OF ZUNIL I AND II

Reservoir temperature and initial pressures allow presentation of a conceptual model for the Zunil I and II geothermal fields. This model is shown in cross section in Figure 6 and can be explained in the following terms:

a) The main upflow of fluids for Zunil I is located in the western part of the field at an intersection of two fault trends. A second heat source appears present near well ZCQ-2 in the northwestern part of Zuni I and may be an extension of the main upflow.

b) A thermal anomaly is present near the SE area of Zunil II and may indicate a possible upflow of fluids for Zunil II. Pressure potentials are higher in the southeast area with a downslope in the northwest direction. This may indicate that fluids are flowing out and discharging in faults near Rio Samala.

c) In Zunil I, a deeper more permeable reservoir at liquid conditions lies within the granitic formation at depths greater than 1000 meters with temperatures not exceeding 300°C.

d) The granitic contact with the overlying volcanics is present at 1100 m a.s.l. for Zunil I and at 1800 m a.s.l. for Zunil II. In Zunil I, this contact defines a permeable horizon. Wells with feedzones at this horizon have lower transmissivity and tend to flash in formation.

e) Temperatures in Zunil II are much higher at shallow depths than the eastern side of Zunil I. Extrapolated temperature profiles show that a reservoir may be present at shallower depth than Zunil I. Shallow wells drilled show temperature and pressures at saturation conditions. The reservoir may be hosted in the granitic formation and could be at liquid or close to saturation conditions.

f) A larger, eastwest trending geothermal system is shown for Zunil I and II. The flow of fluids is possibly along permeable fractures associated with a caldera margin of the Zunil Volcano for Zunil II. Pressure potential defines a similar east west trending geothermal system. The fluids in the system are flowing to the northeast from Zunil I and to northwest from Zunil II. The Zuni I and II systems seem to meet beneath the Samala River. This area appears to be the outflow of both systems.

4. VOLUMETRIC ASSESSMENT OF ZUNIL II

A volumetric estimate of the total amount of heat stored in a reservoir above some reject temperature is found very simply by volumetric interpretation of the temperature contours (Grant, et al., 1982). This is a simple quantitative model for calculating the total “stored heat” in a reservoir when very little data is available for the reservoir. The following equations are used to calculate the power potential of a homogenous reservoir by estimating the amount of energy that can be extracted and converted to electricity:

$$E = V\rho_r C_r (1-\phi)(T - T_r) + V\rho_f \phi(h_f - h_r) \quad (1)$$

where E is the stored heat in the system, V is the Reservoir volume, ρ_r and ρ_f are the Density of rock and fluid, C is the heat capacity of rock, T and T_r are initial reservoir temperature and final reference temperature (°C), ϕ is porosity of rock (%), and h_f and h_r are initial fluid enthalpy in the reservoir and at final reference temperature (kJ/kg).

The equation that applies for converting the heat reserve into electrical power is given as:

$$\text{Reserve}(MWe) = \frac{E * \text{Recovery factor} * \text{Conversion efficiency}}{\text{Plant load} * \text{Load factor}} \quad (2)$$

The uncertainty of the reservoir parameters requires that they be estimated. For this reason a Monte Carlo simulation is carried out. The simulation allow for the parameters to vary from a range of possible maximum to minimum values. The values within the range are calculated at random according to a triangular or square probability distribution function. The reserve is calculated several times from equation 4 and 5, for each set of reservoir parameters and the results are plotted as a frequency distribution versus power output.

The distributed frequency and for the potential electrical power for Zunil II are shown in Figure 7. The results of the simulation show that the Zunil II reservoir has a potential between 25 to 45 MWe for 25 years.

Figure 8 shows the cumulative frequency distribution and it indicates that the most likely value for the reserve is 35 MWe. The cumulative frequency graph also illustrates that there is only less than a 10% chance that the reserve will be below 20 MWe. On the other hand, there is a 90 % chance that the reserve will not yield 50 MWe. This means that if the field is planned for exploitation above 50 MWe, an additional reserve volume will need to proven. It is important to point out that this simulation is based on volume estimated calculated by temperature distributions in Zunil II. The previous estimates for the field stated that the total potential for Zunil II is 50 MWe. It is not clear to this report what parameters were used in that study, but most likely are based on a larger volume for the reservoir.

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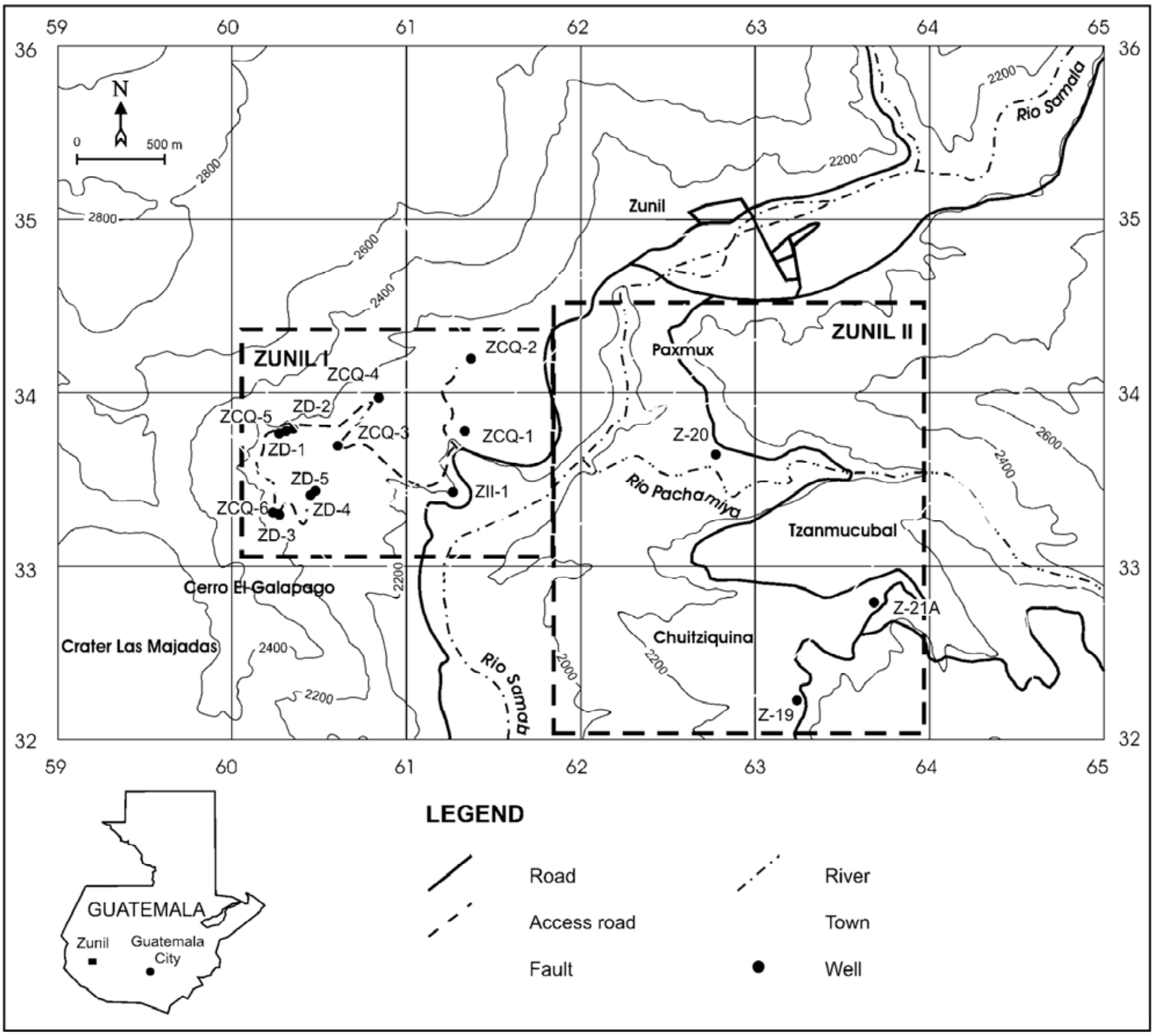

Figure 1: Overview of the Zunil geothermal area showing location of wells and major geologic structures.

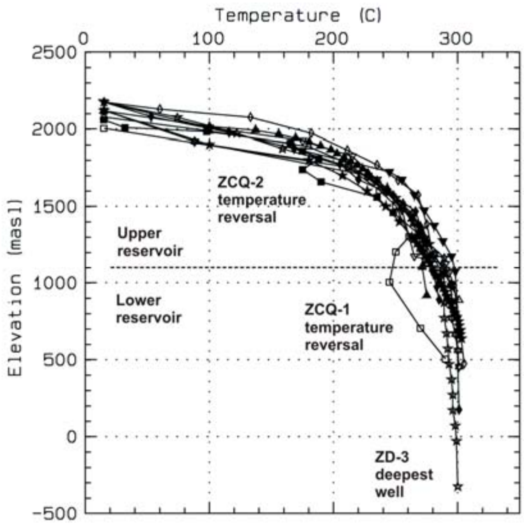

Figure 2: Estimated reservoir temperatures for Zunil I wells.

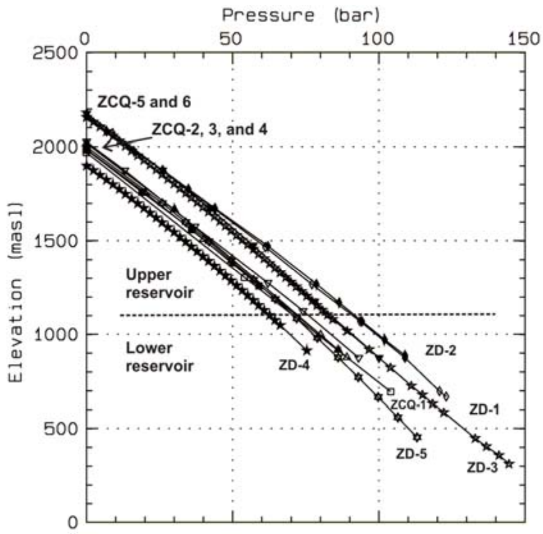

Figure 3: Estimated initial pressures for Zunil I wells.

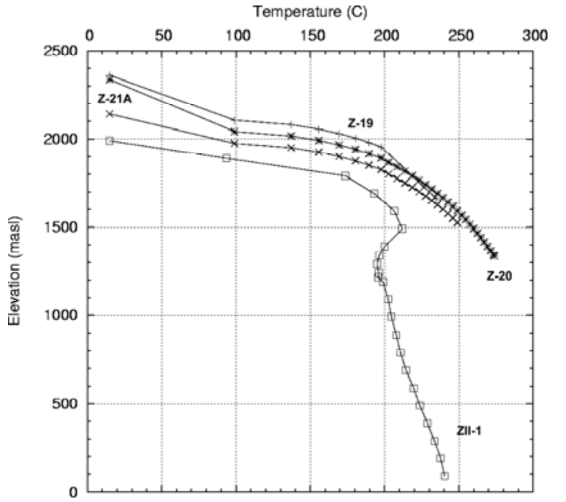

Figure 4: Estimated reservoir temperatures for Zunil II wells.

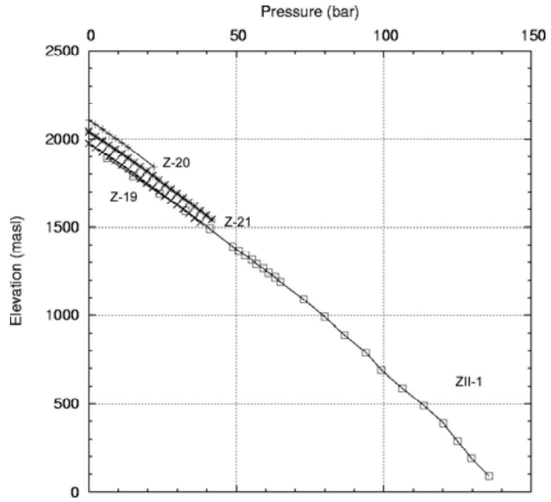

Figure 5: Estimated initial pressures for Zunil II wells.

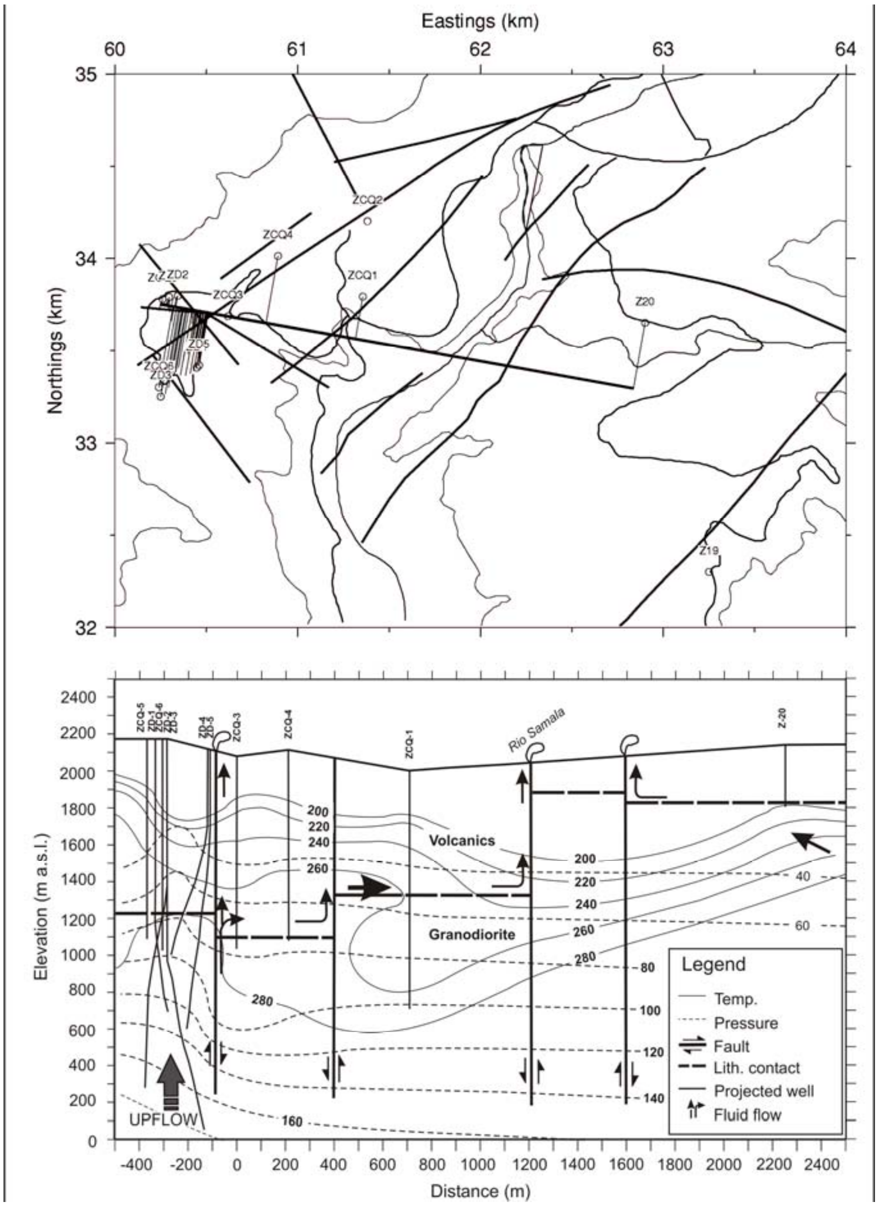

Figure 6: Conceptual model of the Zunil I and II geothermal field.

Table 1: Well characteristics during discharge tests. ZCQ wells were tested in 1989. ZD wells were tested in 1992-93 (Córdon y Mérida et al., 1993). Well ZCQ-2 was tested again in 2004. Water and steam flow are calculated using a separator pressure of 11 bars.

Well No.	WHP (bar)	Enthalpy (kJ/kg)	Qt (kg/s)	Qw (kg/s)	Qs (kg/s)
ZCQ-2	11	1260	48.9	35.3	13.6
ZCQ-3*	7, 9	1492, 1302	22.2, 33.3	14.3, 24.6	7.9, 8.7
ZCQ-4	7	2520	13.9	1.8	12.1
ZCQ-5	10	2436	9.2	1.6	7.6
ZCQ-6	8	1512	13.9	8.8	5.1
ZD-1**	10, 12	1492, 1344	83.3, 91.7	53.7, 65.9	29.6, 25.8
ZD-2**	10, 13	1512, 1492	54.2, 66.7	44.2, 42.7	20.0, 24.0
ZD-3	6	1554	22.2	13.6	8.6
ZD-4	11	1470	25.5	14.4	11.1

* Data values from short term test and long term test, respectively.

** Data values from single well discharge and combined well discharge of ZD-1 and 2.

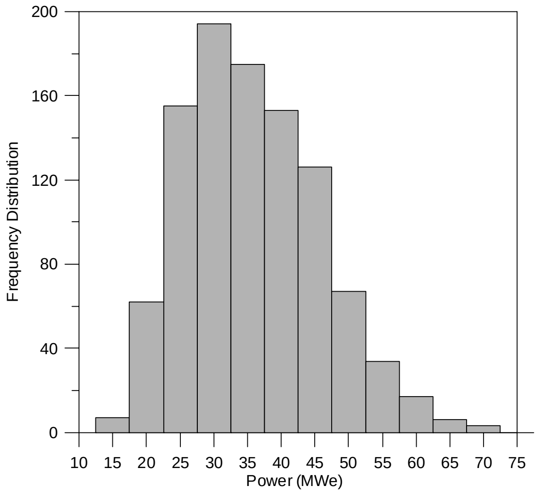

Figure 7: Frequency distribution for the reserve estimate of Zunil II.

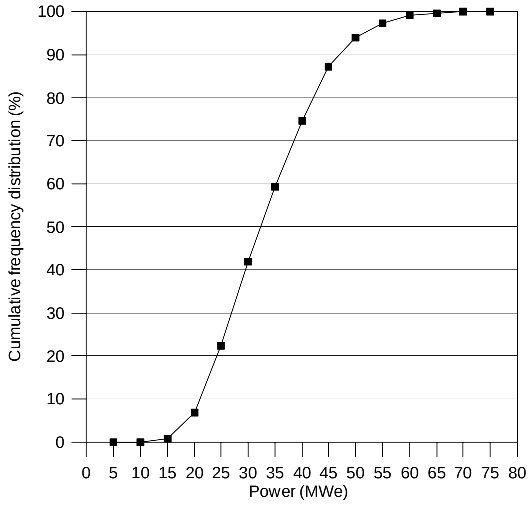

Figure 8: Cumulative frequency distribution for the reserve estimate of Zunil II