NOTICE CONCERNING COPYRIGHT RESTRICTIONS

This document may contain copyrighted materials. These materials have been made available for use in research, teaching, and private study, but may not be used for any commercial purpose. Users may not otherwise copy, reproduce, retransmit, distribute, publish, commercially exploit or otherwise transfer any material.

The copyright law of the United States (Title 17, United States Code) governs the making of photocopies or other reproductions of copyrighted material.

Under certain conditions specified in the law, libraries and archives are authorized to furnish a photocopy or other reproduction. One of these specific conditions is that the photocopy or reproduction is not to be "used for any purpose other than private study, scholarship, or research." If a user makes a request for, or later uses, a photocopy or reproduction for purposes in excess of "fair use," that user may be liable for copyright infringement.

This institution reserves the right to refuse to accept a copying order if, in its judgment, fulfillment of the order would involve violation of copyright law.
CHARACTERISTICS OF THE ZUNIL GEOTHERMAL FIELD (WESTERN GUATEMALA)

H.R. Bethancourt*, E. Domingo**

* INDE, Instituto Nacional de Electrificación, Guatemala, C.A.
** ELC-Electroconsult, Milan, Italy

ABSTRACT
The Zunil geothermal field represents the marginal, shallow expression of a vast geothermal complex buried beneath active volcanic edifices (Cerro Quemado, Volcán Santa María, Western Guatemala) some kilometers to the west. The area lies at the edge of a tecto-volcanic depression where some 1,000 m of Tertiary and Quaternary volcanics are underlain by a granodioritic basement. High temperature geothermal fluids (over 280°C) reach the field from the west, upflowing along the inclined contact between the granodioritic and the overlying volcanics, and along fractures in the basement itself. A conglomeratic layer at the volcanics/basement contact, and the underlying weathered cap of the basement form the only permeable horizon of the succession; this horizon forms the local reservoir tapped by the productive wells. Its reduced thickness (around 50 m) allows for a limited fluid storage such that field production relies on external recharge along the permeable horizon and underlying fractures in the granodiorite.

Production testing and simulation models indicate a fairly rapid evolution of reservoir conditions from the liquid to the steam phase, due to pressure drawdown, in its turn due to a restricted inflow. The phenomenon determines an upgrading of the fluid enthalpy, but a decline of mass output. Simulated reinjection into the reservoir proved to be an effective measure to slow down such an evolution and optimize the field exploitation.

INTRODUCTION
Active volcanism and widespread hydrothermal manifestations instigated geothermal exploration in the Zunil area. Systematic investigations carried out by INDE (Instituto Nacional de Electrificación) in the period 1975-79 produced favourable indications on the existence of an exploit-able geothermal field. Exploratory and evaluation drilling, executed in the years
1980–81, proved the occurrence of a geothermal reservoir, suitable for power generation.

GEOLoGIC OUTLINE

As shown in Fig.1, the Zunil geothermal field is located on the southern edge of a fault-block ("Bloque de Atitlán"), which occupies an intermediate position between the large inland Paleozoic plateau ("Meseta de Huehuetenango") and the Quaternary volcanic belt ("Vertiente de los Volcanes"). The echelon fault arrangement of the region, downstepping towards the Pacific Ocean, is the result of NW-SE and E-W tensional faulting which was active since Tertiary and which also gave origin to the volcanic activity. During Tertiary, such an activity was mainly of the fissural type, with deposition of extended andesitic lava flows on the top of the Cretaceous basement. It evolved into central type activity in the Pleistocene, with growth of large edifices, now deeply eroded. The most recent volcanic centers are aligned along NE-SW axes, intersecting the older regional tectonic trends. During Quaternary, the volcanism evolved towards more acidic products, and the last activity generated mainly dome-type volcanoes, such as the Cerro Quemado complex (active until late last century) and the Santiaguito, a lateral cone of the large extinct Santa María strato-volcano, which shows an almost continuous explosive activity.

As shown in Fig.2, the explored geothermal field is located on the southeastern margin of the Cerro Quemado dome complex which occupies the center of a volcanic-tectonic depression. Exploratory wells confirmed that the granodioritic basement...
gradually rises towards the east of the field, outcropping 2.5 km further east. Following the attitude of the basement, the overlying volcanic cover thins in the same direction, its thickness ranging between 1,000 and 800 m. Schematically, the stratigraphic sequence is the following:

- Quaternary volcanics ( dacitic and rhyodacitic lavas, pyroclastics): 500-600 m;
- Tertiary lava flows, mainly andesitic: 300-400 m;
- Basal conglomeratic deposits, made of volcanic and granitic fragments: 0-50 m;
- Cretaceous granodioritic basement.

The field appears to be weakly affected by faulting and fracturing, which may be partly explained by the presence of the rigid granodioritic mass at shallow depth.

GEOTHERMAL MANIFESTATIONS AND GEOCHEMISTRY OF FLUIDS

The Zunil geothermal system manifests itself in the form of steam manifestations and hot and warm springs. Most of the hot springs are located on the eastern side of the field, along the deep cut of the Sama-16 River, while steam vents occur within the drilled area (see Fig.3).

With few exceptions, the chemical composition of the springs indicates an origin from shallow, fresh water aquifers heated by conduction, with a possible minor contribution of deep geothermal fluid. The geothermal wells showed that the latter is constituted by a NaCl water. Its concentration (TDS = 3,500 ppm), appreciably lower than in other known geothermal fields of Central America (Ahuachapán: 19,000 ppm; Momotombo: 8,000 ppm), may be explained by a relatively fast circulation in contact with the granodioritic basement, less susceptible to leaching than volcanic rocks.

The type C springs, located along one of the few deep faults, discharge a mixture of deep geothermal water and fresh water (see Fig.4).

THE GEOTHERMAL SYSTEM

The combined data from surface and well studies resulted in the interpretative scheme for the field shown in Fig.6.

The Zunil field receives its fluid supply by lateral migration from a source area which can be identified with the volcanic axis Cerro Quemado-Volcán Santa Maria and its associated system of faults and fractures, which have created the conditions for an active vertical circulation and a considerable accumulation of fluids in the underlying formations.
The migration of fluids from the source area towards the Zunil field occurs along the contact between the basement and the volcanic cover, where the basal conglomerate and the weathered cap of the granodiorite constitute a continuous permeable horizon, and along open fractures within the granodiorite itself.

The circulation scheme, based on geological and hydrogeological considerations, is also supported by the following facts: the isotherms shape across the field (see Fig.5), the increasing temperatures westwards, the secondary minerals suites suggesting a hot inflow from the west, the temperature inversion in the upper basement, indicating a hot flow on the top of a cooler surface. Such a feeding mechanism has an important bearing over the exploitability of the field: the fluid extraction rate is directly controlled by the velocity of the recharge from the source area, the storage capacity of the Zunil reservoir being rather limited.

**PRODUCTION CHARACTERISTICS**

Six wells were drilled to evaluate the geothermal aquifer. Due to topographic restrictions, an area of only 2 km² was accessible for drilling. All the wells reached the granodioritic basement, and one penetrated deep into it. Five wells resulted productive with different characteristics. Two wells (4 and 5) produce dry saturated steam, while the others, a mixture of steam and water (see Table 2).

The wells confirmed the existence of a thin permeable layer coincident with the basal clastics, while the overlying volcanic cover resulted almost totally impervious.

Reservoir testing indicated a fast and pronounced pressure drawdown caused by production, which denoted both a reduced local availability of fluid and a restricted inflow. As a consequence of the strong pressure drawdown (of the order of tens of bars), there appeared the formation of steam in the reservoir, which introduced an additional obstacle to fluid circulation, due to the lower $\rho/\mu$ ratio of steam with respect to water. This is the case of well No 5, which immediately reached dry steam production, due to the limited influx of fluid from the surrounding area. On the contrary, well No 4 produces dry steam from an upflow zone, intersected at 600 m depth, where, due to the reduced hydrostatic pressure, flashing occurs in the formation.

The upflow is clearly reflected by the isotherm "nose" visible in well No 4 (Fig.5). The analysis of the reservoir conditions and the simulation of its future behaviour by means of mathematical models showed that the field would evolve towards a rapid increase in enthalpy and a progressive decline of production, which would limit its power potential. Rejection into the reservoir of the residual water looked as an effective measure to control vaporization in the formation and restore pressure to the field.

Reservoir behaviour was simulated at an extraction rate of 125 l/s and simultaneous reinjection of 100 l/s. The results showed that injection appreciably delays vaporization in the formation, assuring a higher margin of "exploitability" to the field.

**SELECTED REFERENCES**

