Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

PRACTICAL USES OF CLAY MINERALS AT THE MIRAVALLES GEOTHERMAL FIELD, COSTA RICA

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Key Words: clay minerals, Costa Rica, geology, geothermometers, illite, smectite, interstratification, Miravalles Geothermal Field.

ABSTRACT

In geothermal resources development the different hydrothermal alteration products are of interest as a source of information. Due to their formation conditions, the clay minerals have great relevance as geothermometers, allowing information top be obtained related to the existing formation temperature of the rocks during the drilling processes.

This paper presents clay minerals data for the Miravalles Geothermal Field, where there is a relationship between the different clay minerals and the temperature variations with depth. The method developed included the elaboration of tables for an easy correlation between the diffractograms results and the estimation of the rock formation temperature. The geothermometer developed has proved to be reliable for the case of the Miravalles Geothermal Field, in the temperature range of 150-220 ºC. The application of this method during the drilling process allows continuous information to be obtained on the existing clay minerals, the thermal evolution of the rock formation and the determination of commercial temperatures for geothermal exploitation. The method also reduces considerably the direct temperature measurements during the drilling, and at the same time reduces the breakdown risks, drilling time and the final costs of the well. Finally, the rock formation temperatures inferred can be used for modeling purposes, giving an idea of the thermal behavior of the field some time before the thermal recovery and stabilization of every well.

1. INTRODUCTION

Minerals are products of natural physical and chemical processes, whose formation depends on very assorted conditions. These conditions are determined by the components concentration, temperature, pressure, permeability and the interaction with the hosted rocks. The formation of the minerals is not given chaotically in nature, but answers to specific conditions. Understanding and interpretating these conditions has great practical value, since it helps us to deduce the characteristics of the rock surroundings, in a rapid and economic way.

Among the alteration products typically formed during hydrothermal processes are the dioctahedral clay minerals (for example, illite and smectite). Characteristic of these minerals is that their formation is determined by the pressure and the temperature, the latter having the greater influencing factor (Harvey & Browne, 1991). Due to this, the study of the clay minerals has considerable importance, since through the determination of the different species the temperature and the composition changes of the surroundings in which they were formed can be deduced. In addition, an adequate identification and zoning of these minerals facilitates their treatment during the well drilling process.

The clay minerals, due to their type of crystallization, do not permit a clear identification by optical microscopy. To accomplish a detailed study of the clay minerals, it is necessary to utilize both separation and identification techniques. This involved size separation followed by X-ray diffraction analysis.

2. GEOLOGICAL SETTING

The Miravalles Geothermal Field is a typical high-temperature liquid-dominated reservoir, located in the northwest part of Costa Rica (Figure 1). Drilling of the first deep exploratory wells dated from 1980, but it is not until 1992 that was begun the extensive drilling with exploitation purposes. The first geothermal plant was commissioned in 1994, and to date the total installed capacity reaches 110 MWe.

The field is confined to a caldera-type collapse structure of 15 km diameter. It was formed about 600 000 years ago with the eruption and deposition of pyroclastic flows. A caldera collapse of over 1000 m has been estimated (ICE and ELC, 1986).

Associated with, or soon after, the caldera formation was a subvertical fracture striking in a NS, to NWW-SSE direction toward the east of the caldera, giving rise to a graben which extends southward beyond the caldera margin (graben La Fortuna).

In a second cycle, volcanic activity was concentrated in the east-giving rise to the andesitic complex of Cabro Muco-la Giganta, followed by the emissions of the Paleo Miravalles. Both are located on a system of faults and fractures trending SW-NE.

In the last 50 000 years, the Miravalles andesitic stratovolcano (2028 m.a.s.l.) was formed. This third cycle culminates with an explosive-effusive activity associated with lava flows and thin pumice deposits which occurred in the Santa Rosa area about 7 000 year ago. During this period, the N-S tectonic regime was reactivated producing a system with an E-W trending fault (ICE and ELC, 1986).

3. METHODOLOGY

During the early years of the Miravalles field development, hydrothermal clay separations and studies were not performed. Therefore, the first step in developing a clay mineralogy program was to adapt a method for separating the clay fraction from the rock samples obtained from the drilling cuttings. Clay separates were prepared by dispersing the whole rock in water and separating a fine fraction. This fraction concentrates the clay minerals (Moore and Reynolds, 1991). The method prepares a sample ready for diffractometry in about 80 minutes. This time can be optimized by around 25%, upon increasing the capacity of the centrifugal facility.

Figure 2 presents rock samples diffractograms and their corresponding phyllosilicate fraction diffractograms.

Following the study, rock samples of all the existing wells in Miravalles were selected. 578 samples from 27 wells were used. The phyllosilicate fraction of these rock samples were separated for further diffractometric study, both the dry samples as well as the ethylene glycol impregnated ones. Taking of rock samples answered to the individual conditions found in each well, this varied from 6 to 100 meters, and greater emphasis was given to the transition zones from pure clay species to interstratificated species.

4. RESULTS

From the interpretation of the data it was determined that the clay minerals in the Miravalles Geothermal Field are represented by:

- Smectite: it is found in all the wells of the field (Figure 3A).
- Illite/smectite interstratification: is found in all the wells of the field; its percentage of mixture varies with the increase in temperature (Figures 3B, 3C, 3D, 3E, 3F, and 3G).
- Chlorite/smectite interstratification: is not characteristic of the field, and is not found in all the wells; where it is presented makes it of irregular way.
- Illite: is found in all the wells of the field (Figure 3H).

Other phyllosilicates found are the kaolinite (which is found in some wells solely in shallow levels), and the chlorites (whose presence is common at different depths in all the wells of the field). These minerals are only reported since they did not form part of the objectives of this investigation.

The last part of this study consisted of the analysis and interpretation of the obtained data from the diffractometric analysis.

Distribution profiles of the clays according to the depth were analyzed (Figure 4); and the data of these profiles were interpreted based on existing wells temperature surveys. For practical purposes, the thermal stability range of the smectite and the illite/smectite interstratification and of illite, are shown in Figures 5 and 6. These figures relate the formation temperature estimated by clays with static temperature surveys.

Finally, a graph that comprises the interpretation was developed. It relates directly the distance between the first and second diffraction of the spectrum (2), the illite percentage in the illite/smectite interstratification (Moore and Reynolds, 1989) and the temperature estimation according to the different illite percentages (Figure 7).

5. DISCUSSION

The analysis showed that the clay species can be used during the drilling process as a reliable mineral geothermometers for the thermal evolution of the rock formation. The geothermometer works at the Miravalles Geothermal Field in the temperature range between 150 and 220 ºC.

The study of the clay species has been used in the Miravalles Geothermal Field from 1993, for the following purposes:

- To obtain, during the drilling process, reliable data on the existing formation temperatures, the thermal gradient, and identify thermal anomalies with either negative or positive character (Figure 4).
- As a direct contribution to the well construction work, while knowing the type of clays and their crystallization state, it can be offered the adequate treatment to these minerals during the drilling process, with the objective of eliminating its negative effects. Additionally, these same analysis offer greater information on collapse problems of the most shallow zones, those which generally are characterized by the predominance of the alteration of the rock to momtmorillonites.
- To obtain data for modeling, in the elaboration of profiles (Figure 8) and isothermal surfaces (Figure 9), with the advantage of the fact that the same are accomplished during the drilling of the wells. This later factor permits a clear idea of the field thermal behavior before the direct temperature surveys, which are accomplished after the thermal stabilization of the well, which can take weeks or months after itscompletion.

This geothermometer has been used continuously in Miravalles since 1994, giving reliable results in another 17 wells drilled to date.

6. SUMMARY

In the Miravalles Geothermal Field a geothermometer was developed, which uses the clay minerals found during the geothermal wells perforation.

The methodology developed for this geothermometer includes the separation of the clay minerals from the drilling cuttings, the development of analysis techniques and the establishment of relationships between the clay minerals, and the temperature variations with the depth.

To date, the geothermometer has been tested in 43 wells drilled in Miravalles. This geothermometer has proven to be reliable in the Miravalles Geothermal Field, within a temperature range of 150-220 ºC.

The study and interpretation of the clay species in geothermal fields is justified from practical, economic and investigative point of views. This is now another tool used in routine drilling operations, that allows:

- To obtain constant information about the rock formation temperatures over the entire wellbore length, while drilling.
- To obtain information related to the types of existing clays for their adequate treatment.
- A considerable reduction of the downhole temperature surveys during the drilling of the well. This reduces the risks, the drilling time and the costs of the well, by tens of thousands dollars.
- To obtain information more quickly to support decision making while drilling.
- To obtain information for field modeling effects.

ACKNOWLEDGEMENTS

We are grateful to geologist Eduardo Vega and Dr. Oscar Murillo for his help and careful review of this paper.

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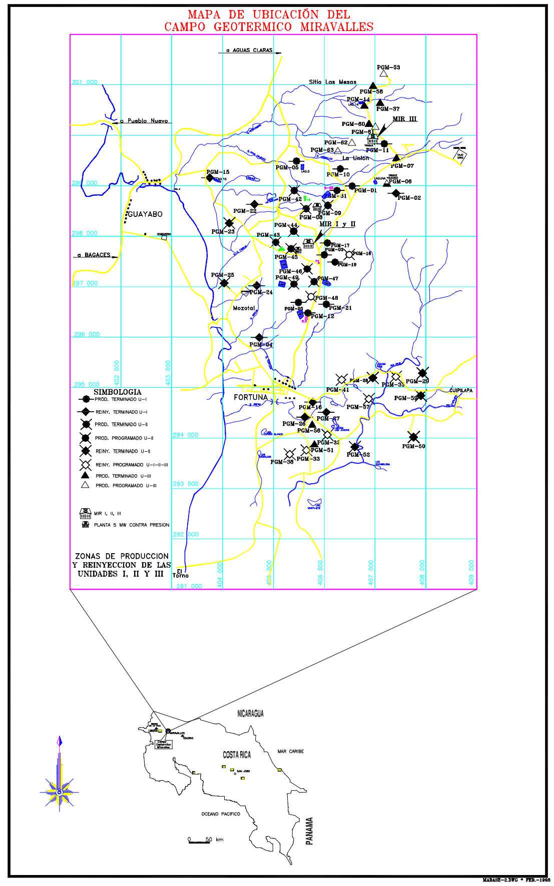

Figure 1. Location Map of the Miravalles Geothermal Field

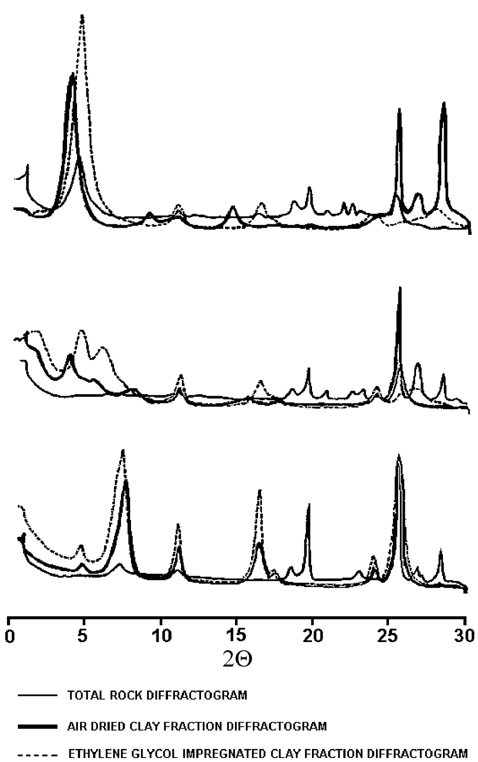

Figure 2. Sample Diffraction Patterns

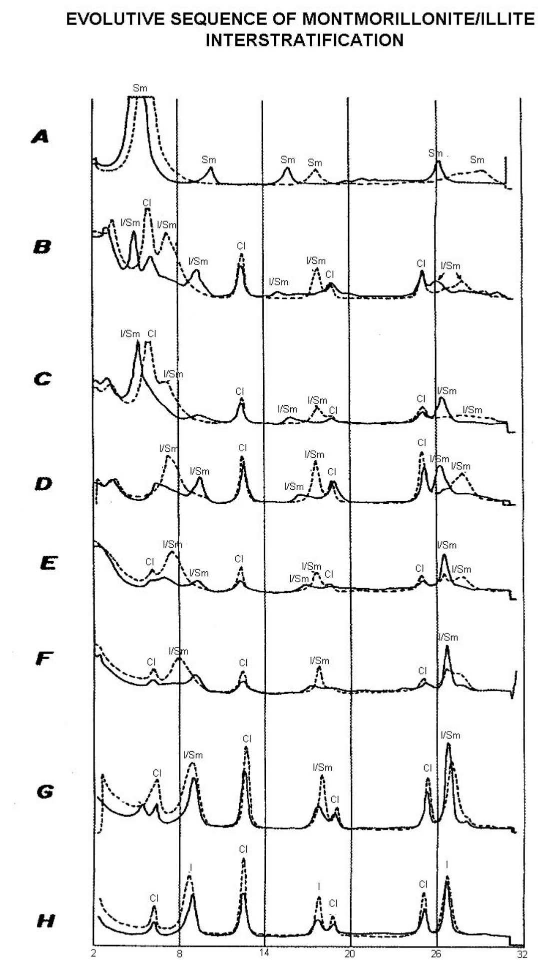

Figure 3. Interpretation of the Different Clay Minerals

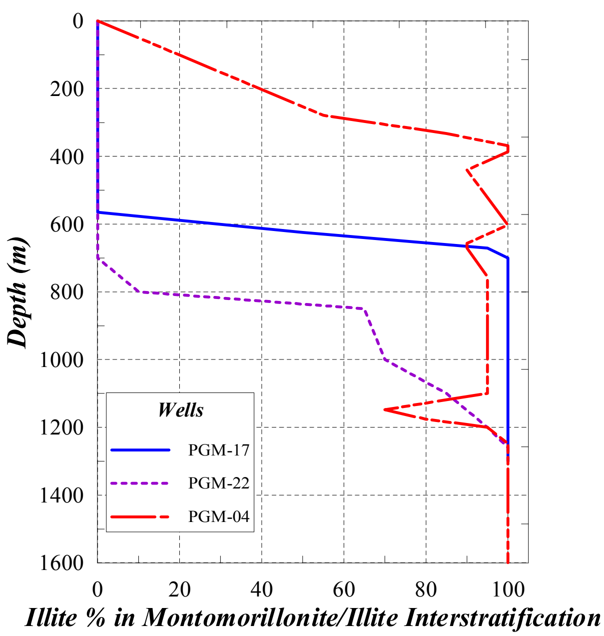

Figure 4. Illite % in the Montmorillonite/Illite Interstratification in Some Wells of the Miravalles Field.

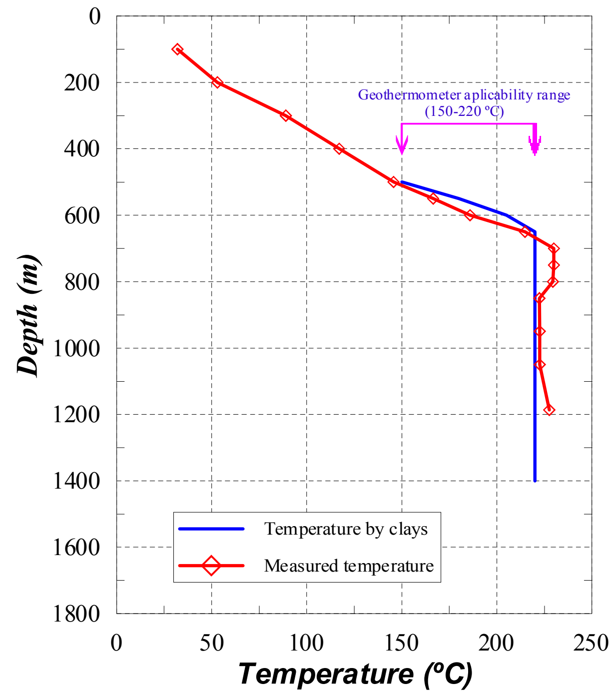

Figure 5. Comparison of the measured Static Temperature and the Formation Temperature Estimated by Clays in Well PGM-21.

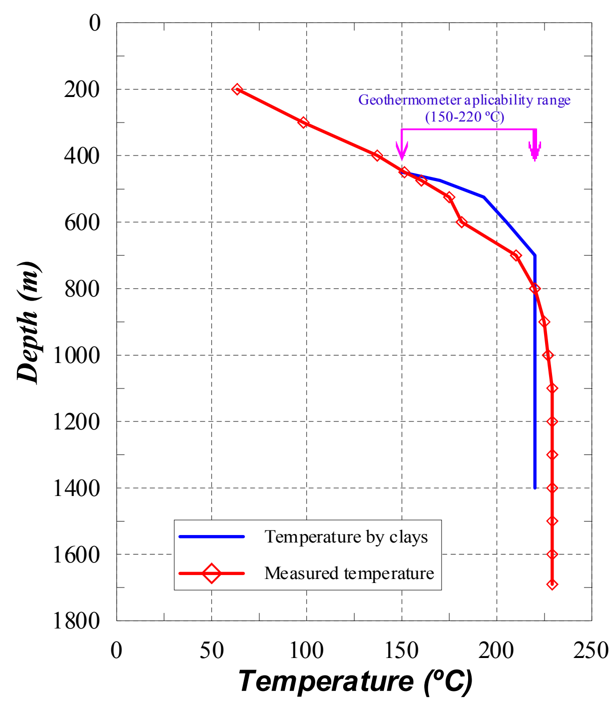

Figure 6. Comparison of the Measured Static Temperature and the Formation Temperature Estimated by Clays in Well PGM-46.

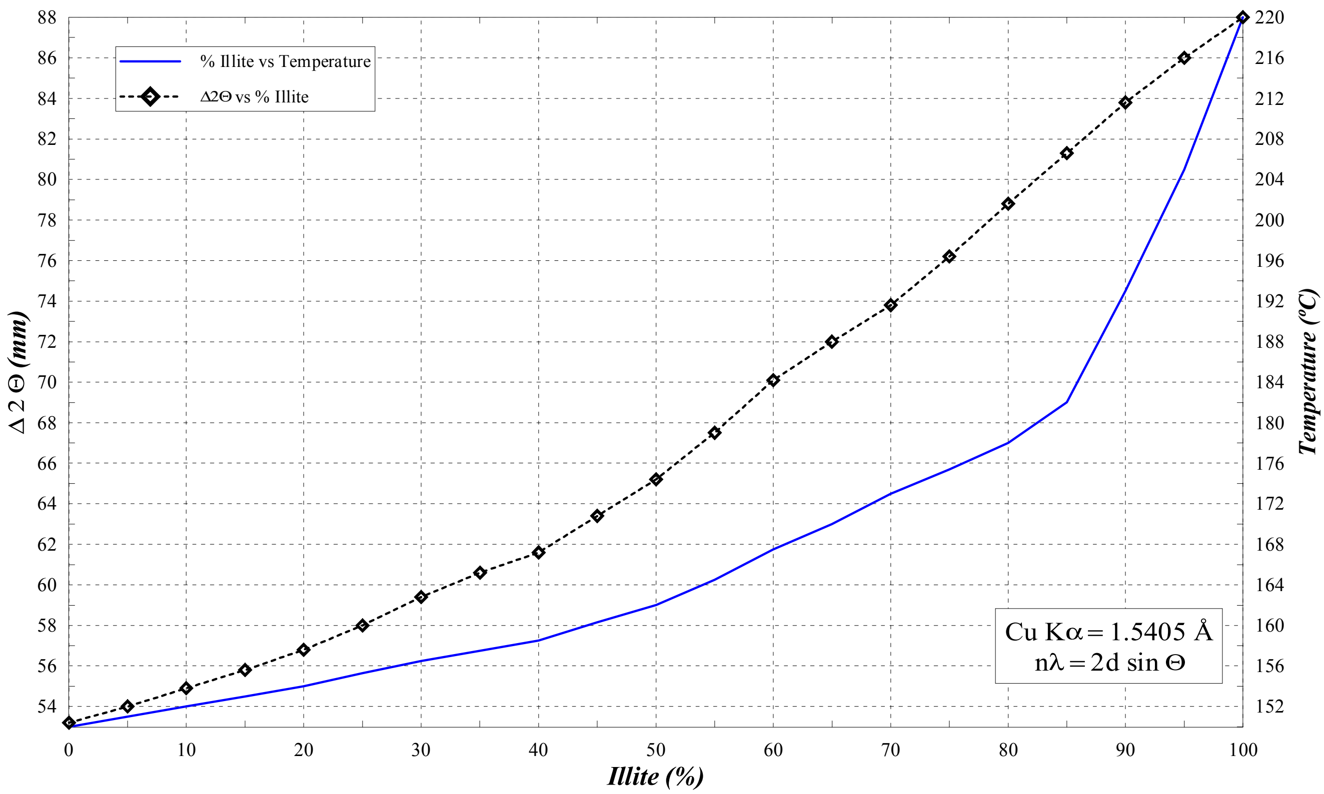

Figure 7. Δ2Θ/Illite/Temperature Relationship for the Miravalles Geothermal Field

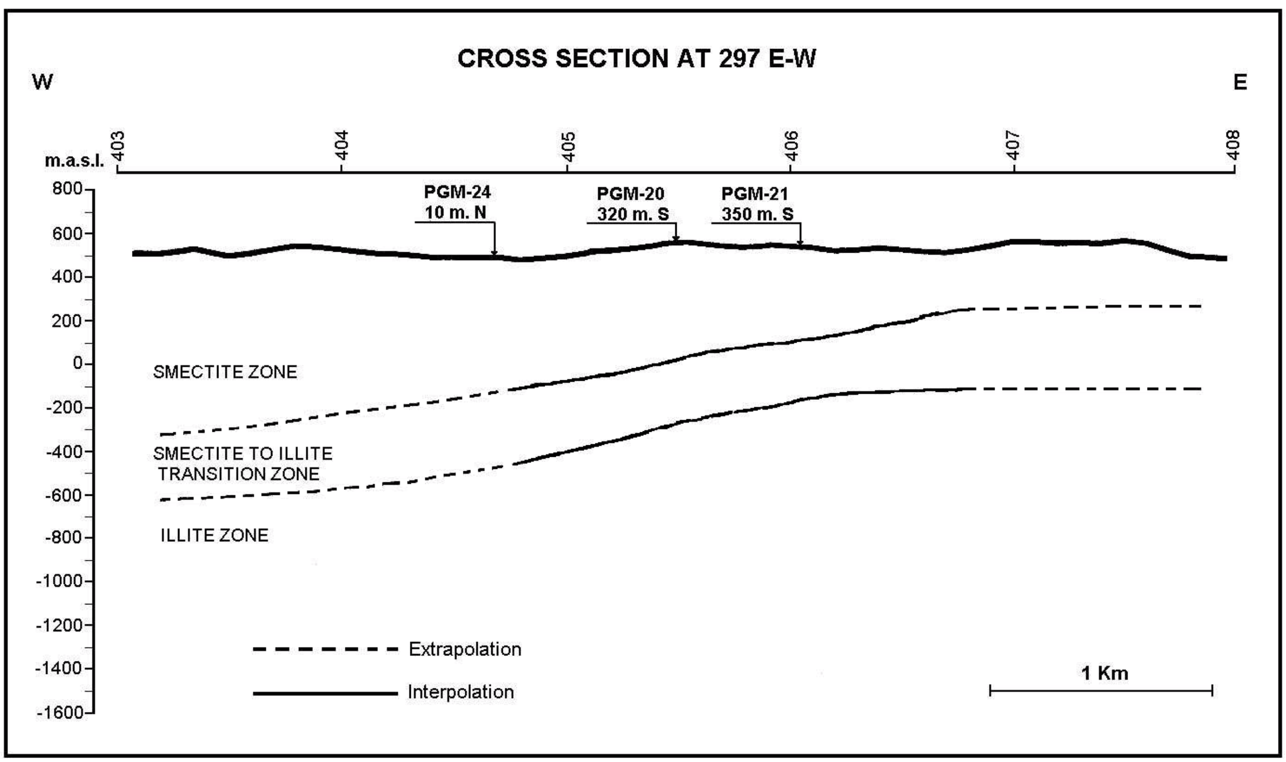

Figure 8. Cross Section of Clay Minerals Distribution in the Miravalles Geothermal Field.

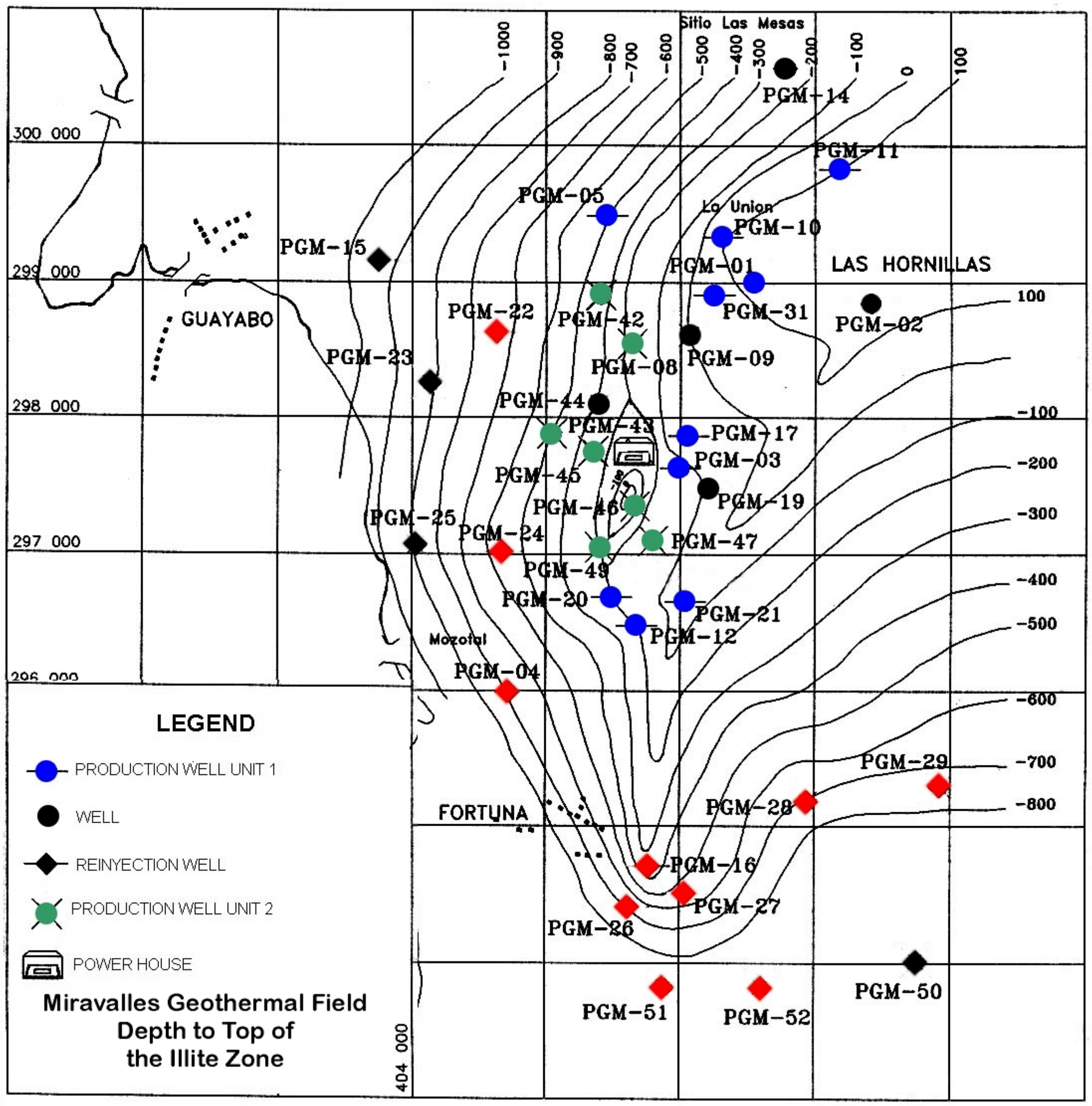

Figure 9. Depth to Top of the Illite Zone.