CLAY MINERALS, FLUID INCLUSIONS AND STABILIZED TEMPERATURE ESTIMATION IN TWO WELLS FROM LOS AZUFRES GEOTHERMAL FIELD, MEXICO

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ABSTRACT

The objective of this work is to test the application of different geothermometers on the same samples from two wells from the same reservoir and to compare the obtained results. Wells A23 and A9 were chosen because they intersect a thick layer of rhyolites and andesites respectively,
The clay minerals consist of: kaolinite, smectite and illite in the rhyolites and smectite, illite and chlorite in the andesites. Fluid inclusions in quartz contain low salinity waters and have homogenization temperatures of up to 345°C in the deepest samples. T,, increases as a function **of** depth, except in well **A23** between 500m and 1100m where the temperature remains almost constant, prohahly due to convection. The stabilized temperatures were estimated by mathematical simulation using temperature logs. For comparison, results were summarized in graphs.
Based on the relative proportion **of** clay minerals it is possible to define ranges of temperature and to draw a thermal profile which is plotted and compared with those given by fluid inclusions, present-day measurements and by stabilized temperatures. Results indicate that microthermometry may overestimate actual temperatures although ad underestimation of actual temperatures is also possible.

Key words: Clay minerals, fluid inclusions, Los Azufres, geothermometers.

1. INTRODUCTION

The Los Azufres geothermal field (LAGF) is presently the second geothermal resource within the Republic of Mexico. The first well was drilled by the Comisión Federal de Electricidad (CFE) of Mexico in 1976. Since then, 62 wells ranging in depth between 600 to 3544m (A44) have been drilled in an area of almost 40 km².
Most of the wells are located along and between two well defined zones of steam discharge. These are the Marítaro zone (close to the Maritaro Fault, F.M.) in the north; it is characterized by wells which produce water-steam mixtures and in the south the Tejamaniles zone (between the Tejamaniles and Agua Fria Faults, F.A.F.) by dry-steam wells.
The exploitation of energy in the LAGF started in 1982 when a 5 MW wellhead generator unit was installed (Alonso-Espinoza, 1985). At present the field has a total installed capacity of 90 MW.

The LAGF has given an excellent opportunity to perform a variety of scientific studies through its exploration, development and exploitation stages. Mineralogical and fluid inclusion studies were carried out in order to establish the distribution of hydrothermal mineral zones and thermal profiles in different sections of the field (Cathelineau et al., 1983 and Cathelineau et al., 1989). Phyllosilicates formed as products of hydrothermal alteration in active geothermal areas are of great interest, since their occurrence is related to the temperature of their formation. Previous studies of phylosilicates at LAGF have focussed on their dependence on temperature and rock composition (Izquierdo and Cathelineau, 1987), their characterization (Izquierdo, 1989) and their application as geothermometers (Cathelineau and Nieva, 1985; Cathelineau and Izquierdo, 1988).
Cathelineau and Izquierdo (1987) based on a systematic fluid

PHYLOSILICATES	TEMP. °C
Kaolinite + Esmectite	< 200
Illite + Esmectite or Chlorite + Esmectite	200 - 250
Illite or Chlorite	> 250

Table 1. Thermal zones in Los Azufres Geothermal Field, based on the relative proportion of phylosilicates in the clay fraction.

The objective of the present study is to compare data obtained when different geothermometers are used in the same samples of the same wells and, in a future work to calibrate clay mineral associations as thermoindicators. Therefore, it is necessary to determine which temperatures are the most reliable and representative of the reservoir.

In order to apply the different geothermometers and to characterize the clay minerals formed by hydrothermal alteration on the reservoir rocks, two wells were selected. One is drilled mostly in rhyolites (A23) whereas the other is in andesites (A9).

2. STUDY AREA

The Los Azufres Geothermal Field is located in The Sierra de San Andrés in the Michoacin State of Mexico. It is in the geological province known as Mexican Volcanic Belt *(see* inset of Figure 1).
The geology of the LAGF has been described by several authors (Camacho, 1979; Gutiérrez and Aumento, 1981; Dobson and Mahood, 1985 among others). The lithologic successions consist of an andesitic basement overlain by rhyolitic and dacitic domes and flows, and a volcano-sedimentary sequence with interlayered ashes and pumices (Fig. 1). Thus, most rocks at depth are andesites with a thin cover of rhyolites mostly in the range 0-500m depth in the central part of the field. Although they have been encountered in some wells down to 1 km (well A23). These rocks belong to thecalk-alkaline series of the Mexican Volcanic Belt.
In the present study, wells A23 and A9 were selected because the former penetrates a thick sequence of rhyolites whereas the latter was drilled mainly on andesites. Well A23 is located near the center of the field, 200m from the San Alejo fault, and has a depth of 1825m. The lithological column of well A23, from the surface to 1140m, consists of rhyolites and from this depth to the bottom of the well the rocks are andesites. Well A9 is located in the northern part of the field between the El Chino and El Gallo faults. This well was drilled mostly throughandesites; its total depth is 2591m.

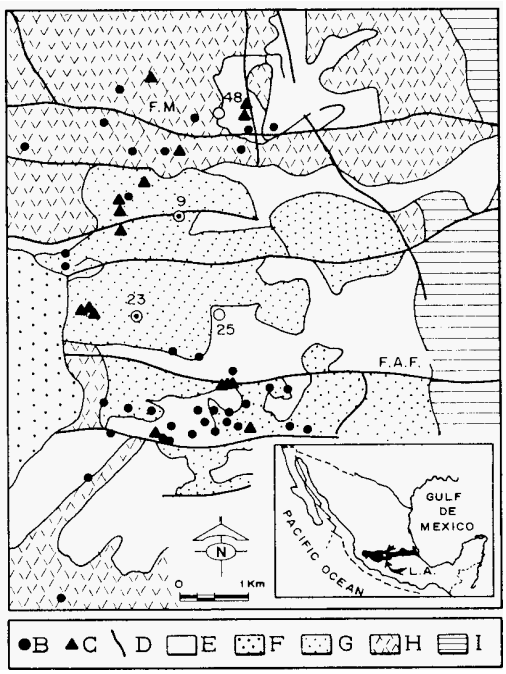

Figure 1. Simplified geological map of the Los Azufres Geothermal Field. It shows the locations of wells A23 and A9. The inset depicts the Mexican Volcanic Belt, where the study area is located. The symbols correspond to: Drilled well (B), surface emission (C), major fault (D), tuffs (E), vitreous rhyolite, flow rhyolite (G), andesite (H) and dacite (I).

3. TECHNIQUES

Microthermometry of fluid inclusions

CFE provided cuttings, at 100m intervals, obtained during the drilling of the two wells. Fluid inclusions were analyzed systematically in authigenic transparent minerals which were separated manually under a binocular microscope. The tiny fragments were, as much as possible, doubly polished. Fluid inclusions were studied mainly in authigenic quartz, using a Chaix-Meca heating-cooling stage. The stage was calibrated for temperatures higher than 25°C using the melting point of organic standards and for temperatures below 0°C with natural and synthetic fluid inclusions. As the fluid trapped in authigenic minerals at Los Azufres is a diluted, gas-poor water, only two parameters were determined for each fluid inclusion: the melting temperature of ice (T_{mi}) and the bulk homogenization temperature (T_h). One important characteristic of most fluid inclusions in Los Azufres is that they are very small and therefore it is frequently difficult to observe the T_{mi}.

Clay minerals determination

The phylosilicates present in the clay fraction of the cuttings, were characterized by X-ray diffraction. In order to eliminate contaminant drilling mud, cuttings were carefully washed with distilled water. Clay minerals were mechanically separated in an ultrasonic bath and by repeated sedimentation. Oriented preparations were produced by pipetting the clay slurry onto a glass slide. All samples were run in a Siemens D500 diffractometer with Ni-filtered copper radiation. Samples were saturated in an ethylene glycol atmosphere at 60°C. To ensure clay identification some samples were heated at 200°, 350" and 500°C. After each treatment, the samples were X-rayed. Estimation of the relative percentages of each clay mineral was made by measuring the linear peak height intensity of the I_{100} of the phylosilicates present in the clay fraction.

Mathematical model for temperature calculation

The model of Ascencio *et al.*, (1994) assumes that the return to equilibrium after a thermal disturbance created by fluid circulation (during the drilling of a well) follows a spherical radial heating pattern and that formation temperatures can be obtained from the intercept of a temperature versus (time)$^{1/2}$ plot. Estimation of stabilized temperatures was made taking into account data logs from the two studied wells.

Temperature logs

The downhole temperature logs were provided by the CFE. They were measured directly in the wells using a Kuster equipment.

Chemical geothermometers.

Chemical composition of produced fluids constitutes one of the early important sources of information, which could be used for temperature estimation. Using the Na-K-Ca geothermometer (Fournier and Truesdell, 1973), only one temperature calculation was made for well A9.

4. RESULTS AND DISCUSSION

Clay minerals formed by hydrothermal alteration in wells A23 and A9 include kaolinite, Na-smectite, illite and chlorite. The relative proportion of each mineral varies as a function of temperature, rock composition and depth. Based on a previous work (Izquierdo and Cathelineau, 1987), temperature ranges were determined from the clay minerals relative proportion.

Fluid inclusions in authigenic quartz from cuttings of wells A23 and A9 consist of two phases (liquid + vapor) at room temperature. Inclusions have very similar volumetric fraction % of the vapor phase, which indicates a trapping of a homogeneous single phase fluid. Thus, most of the inclusions homogenize in the liquid phase. The liquid has a low salinity shown by the high melting temperature of ice (-1 to 0°C).

Figure 2 is a summary of the fluid inclusion and X-ray diffraction data for well A23. For comparison, current temperatures and data obtained from mathematical simulation are plotted on the same figure. Squares indicate the range of temperature in which the high proportion of a clay mineral occurs. Kaolinite and smectite are the main mineral phases present in the shallowest levels and, illite and chlorite at depth. In rhyolites, illite constitutes more than 90% of the clay fraction and is accompanied by small amount of smectite. The chlorite appearance is strictly related to the rock lithology change (rhyolite to andesite) and becomes the main comuonent above 250°C.

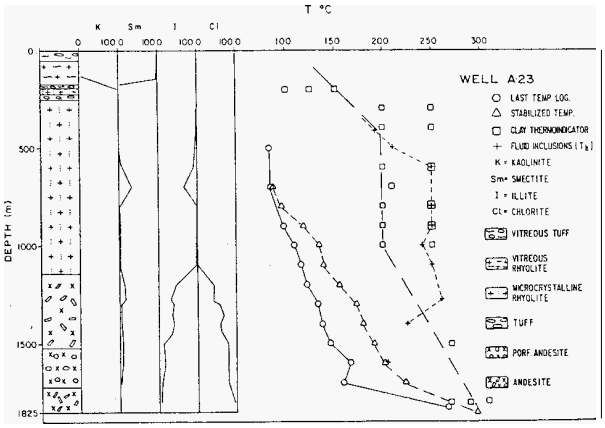

Figure 2. Stratigraphy, clay mineralogy and temperature profiles for well A23.

For well A23, homogenization temperatures show single mode distribution. Table **2** is a summary of microthermometric data for this well.

DEPTH (m)	$T_h \pm 10°C$
420	192
500	220
600	250
700	250
800	250
900	250
1000	240
1100	250
1280	260
1400	225

For this well there is a considerable difference between mineral thermoindicators and current temperatures. Taking into account the range of temperatures where illite occurs as the clay phase, it is in good agreement with fluid inclusion temperatures. If convective heat transfer occurs in rhyolites, temperatures will be constant with depth as this is consistent with the fluid inclusions and high proportion of illite. At deep levels current temperatures and clay thermoindicator are closer, unfortunately at these depths there were no transparent minerals available for fluid inclusion studies.

In general, mineral geothermometers are consistently higher than present-day temperatures. According to Belkin et al. (1985), this may testify to an actual change in the thermal regime at well A23. However, it is also possible that the hydrothermal minerals were deposited by hotter fluids than the present ones.

Results for well A9 are summarized in Figure 3. Kaolinite, Na-smectite, illite and chlorite were identified in the clay fraction of the samples. As can be seen from their relative proportions, the clay mineralogy is dependent on rock composition and temperature. Dark squares show the range of temperature in which a high proportion of the clay mineral may be expected. Kaolinite and smectite are the clay minerals encountered from the surface down to 240m,

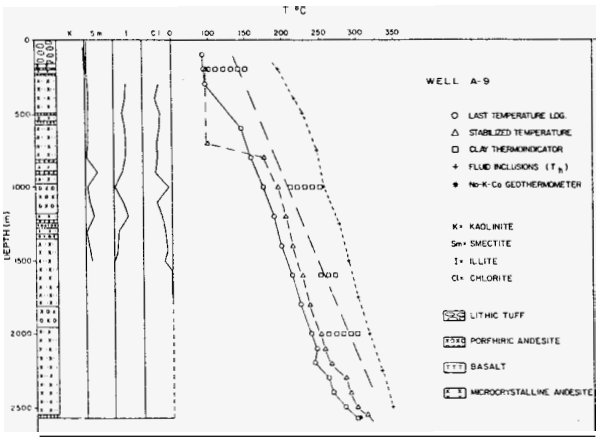

Figure 3. Stratigraphy, clay mineralogy and temperature profiles for well A9.

indicating rock temperatures below 150°C. With increasing depth and temperature there is a mixture of smectite, illite and chlorite formed in a range of temperatures between 200" and 250°C. From 1500m to the maximum depth of the well, chlorite is the main phase favoured by the andesitic rock composition and the rock temperature above 250°C.

As in well A23, fluid inclusions trapped in authigenic quartz are of the two phase type (liquid + vapor) at room temperature. The liquid has low salinity which is shown by the melting temperature of ice (-1 to 0°C). Homogenization temperatures also show a single mode distribution in all samples.
Homogenization temperatures for well A9 are summarized in Table **3.**

DEPTH (m)	$T_h \pm 10°C$
200	184
400	217
500	228
750	246
1000	254
1250	275
1500	288
1750	300
2000	315
2250	332
2500	346

In addition, present-day temperatures are lower than the homogenization temperatures. The temperature range indicated by clay minerals is in between those given by fluid inclusions and by direct determinations. **As** for well A23, the same assumptions can be made. Probably, the hydrothermal minerals have been deposited by hotter fluids than the present ones and furthermore, colder recharge fluids could be entering into the system.

5. CONCLUSIONS

Hydrothermal clay minerals, among other geothermal minerals, may be used as thermoindicators because their structure and chemical composition are sensitive to thermal changes. Temperatures based on the proportion of clay minerals are in good agreement with those proposed for other geothermal systems such as Reykjanes, Iceland. In the two wells studied here, microthermometric measurements on fluid inclusions yielded higher temperatures than the measured values. Possibly, hotter fluids occurred at the moment of hydrothermal mineral deposition. The difference among temperatures could indicate that a cooling has occurred in the reservoir. Although an underestimation of the present-day measurements is also probable.

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