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HYDROTHERMAL MODEL OF THE MOMOTOMBO GEOTHERMAL SYSTEM, NICARAGUA

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ABSTRACT

The Momotombo geothermal field is situated on the northern shore of Lake Managua at the foot of the active Momotombo volcano. The field has been producing electricity since 1983 and has an installed capacity of 70 MWe. The results of geological, geochemical and geophysical studies have been reported in various internal reports. The isotopic studies were funded by the International Atomic Energy Agency (IAEA), Vienna to develop a hydrothermal model of the geothermal system.

The chemical and stable isotopic data ($\delta^{18}O$ and δD) of the geothermal fluid suggest that the seasonal variation in the production characteristics of the wells is related to the rapid infiltration of local precipitation into the reservoir. The annual average composition of Na^+, K^+ and Mg^{2+} plotted on the Na-K-Mg triangular diagram presented by Giggenbach (1988) to identify the state of rock-water interaction in geothermal reservoirs, shows that the fluids of almost every well are shifting towards chemically immature water due to reservoir exploitation. This effect is prominent in wells Mt-2, Mt-12, Mt-22 and Mt-27.

The local groundwaters including surface water from Lake Managua have much lower tritium concentrations than some of the geothermal well fluids, which have about 6 T.U. The high-tritium wells are located along a fault inferred from a thermal anomaly. The tritium concentration is also higher in fluids from wells close to the lake. This could indicate that older local precipitation waters are stored in a deep layer within the lake and that they are infiltrating into the geothermal reservoir.

INTRDUCTION

In the western part of Nicaragua there exists an important Quaternary active volcanic chain, the Los Marrabios Cordillera, which has several high-temperature geothermal resources. The Momotombo liquid-dominated geothermal field in this volcanic chain is located about 80 km northwest of Managua city. The field is situated on the northern shore of Lake Managua at the foot of the active Momotombo volcano. Figure 1 shows the location of the field, wells and major faults; it covers an area of 2 km^2. The first power plant came on line in September 1983; it produced 35 MWe. At present Momotombo has an installed capacity of 70 MWe which is about 30% of the total electricity generated in the country.

Zurflueh and Teilman (1980) summarized the results of geological, geochemical and geophysical studies made during the exploration of the field. The tectonic movements of the region favor the presence of high-temperature geothermal resources. The thermal manifestations: fumarolas, hydrothermally altered areas, thermal springs and warm water wells in the region are associated with the Quaternary volcanism.

Perez (1991) made chemical equilibrium calculations for fluids from four wells to define the state of rock-water interaction. Combredet et al. (1986) studied the petrography and fluid inclusions in four wells Mt-34, Mt-35, Mt-36 and Mt-37. The homogenization temperatures are in the range 160 to 275°C and there was no boiling during the formation of the geothermal system. The Momotombo geothermal reservoir is a sodium-chloride (600-700 ppm) water dominated field. It has two reservoirs with an inflow of cold water from the east and an upflow of hot water from the southwest. Porras-Mendieta (1994) concluded with the ten years production history of the reservoir that the pressure in the shallow part has been dropped more than 20 bars which has produced extensive boiling. There are 39 wells: 9 monitoring, 5 reinjection and 25 production wells.

In this article we present a preliminary interpretation of the chemical and isotopic data to understand the thermal evolution history of the system. The changes in the physical-chemical characteristics of the fluid are used to define the hydrothermal model of the system.

RESERVOIR GEOCHEMICAL EVOLUTION

The geochemical inventory of natural manifestations at the Momotombo geothermal field was conducted in early 1960. In 1974 drilling was started to evaluate the reservoir characteristics. The first electric energy production using geothermal resources started in 1983. In 1986 special attention was given to create systematic records of chemical analyses of the fluid from drilled wells in the field.

Porras-Mendieta (1994) analyses the production and reinjection fluid data of the field. Till 1993, the cumulative mass production from the field is of the order of 80 million tons. The separated water from five productive wells (Mt-23, Mt-27, Mt-31, Mt-35 and Mt-36) has been reinjected to the reservoir through five injection wells RMt-2, MT-6, Mt-10, Mt-15 and Mt-18.

Figure 2(a) and (b) shows the production characteristics of well Mt-12. The two-phase production of fluid has changed to vapor in almost all the wells and, except in this well, well head pressures have dropped. Porras-Mendieta (1994) reported a pressure drawdown of more than 20 bar in the shallow part of the reservoir. Quijano (1989) concluded that the pressure drop has produced boiling in the reservoir with very little transfer of heat from the rocks to the fluid. The concentration of Cl^- in separated water has remained constant in most of the wells. In well Mt-12 fluid Cl^- concentrations have dropped after 1990 (Figure 2(c)) whereas the wellhead pressure has increased, which is very unusual. The measured enthalpy is higher than that calculated with Na-K-Ca and SiO_2 geothermometers (Henley et al., 1984) except in wells Mt-23, Mt-26 and Mt-38. This indicates that the boiling is taking place in most of the wells and the reservoir has been extensively exploited.

The annual average composition of Na^+, K^+ and Mg^{2+} for the well Mt-12 are plotted on the Na-K-Mg triangular diagram presented by Giggenbach (1988) to identify the state of rock-water interaction in a geothermal reservoir (Figure 3). The fluid is shifting towards chemically immature water. The effect is evident in almost all the wells, but it is prominent in wells Mt-2, Mt-12, Mt-22 and Mt-27. This is a clear indication of encroachment of cold water in the reservoir without sufficient time to reach chemical equilibrium.

At the beginning of the exploitation of the reservoir it a seasonal variation was observed in the production characteristics of the wells. This could be related to rapid infiltration of local meteoric water into zones being produced by the wells. It was also considered that declines in production were due to the encroachment of reinjected water into the production zone.

Figure 4 (a) and (b) show the isotopic compositions of fluids from the production wells and natural manifestations in 1989 and 1994, respectively. The isotopic compositions of all the well fluids have shifted towards that of local meteoric water side. This also favors the hypothesis of infiltration of cold meteoric water, which is not getting sufficient time to equilibrate.

In 1994 a sampling was carried out to analysis the tritium concentration in the fluid of six geothermal wells and in the surrounding natural manifestations. The tritium concentration in the local groundwater including surface water form Lake Managua is lower than 1 T.U., whereas in three of the wells, Mt-23, Mt-27, and Mt-31 the tritium concentration is of the order of 6 T.U. These wells are located along a fault inferred from a thermal anomaly. The tritium concentration is also higher in the fluids from wells close to the lake. This could indicate that water from older local precipitation is stored in a deep layer within the lake and that this water is infiltrating into the geothermal reservoir.

CONCLUSIONS

The Momotombo geothermal system is producing electric energy since 1983. The production has declined due to infiltration of cold meteoric water and boiling in the reservoir as a result of extensive exploitation. The geothermal system is characterized as a vertical convective system. The upper part of the reservoir is affected by infiltration of local meteoric water and deep water from Lake Managua. Further investigation are required to define the recharge zone and the actual state of rock-water interaction.

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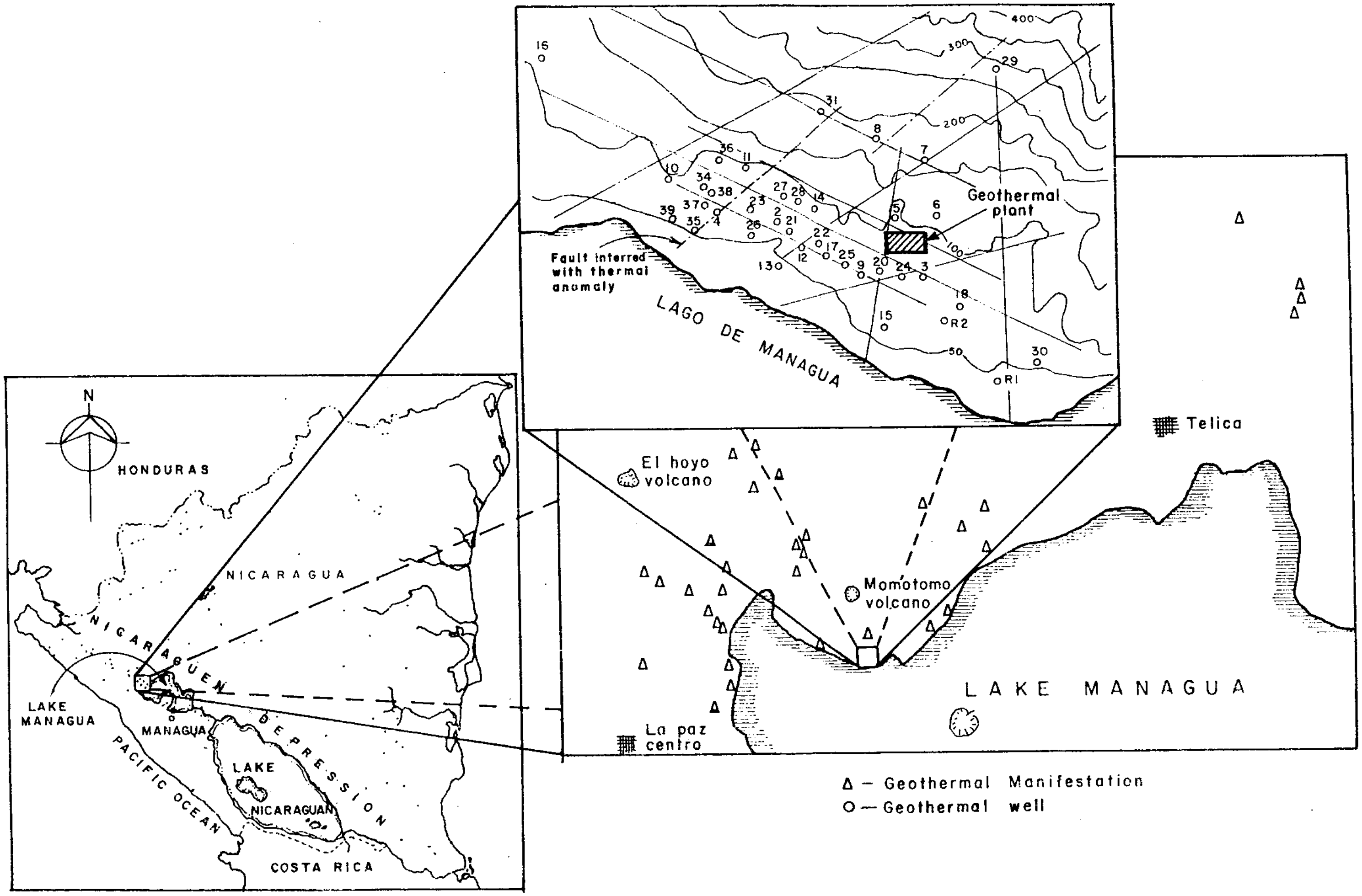

Figure 1: Location map of the Momotombo geothermal field. Also shown are the wells and the main faults in the field.

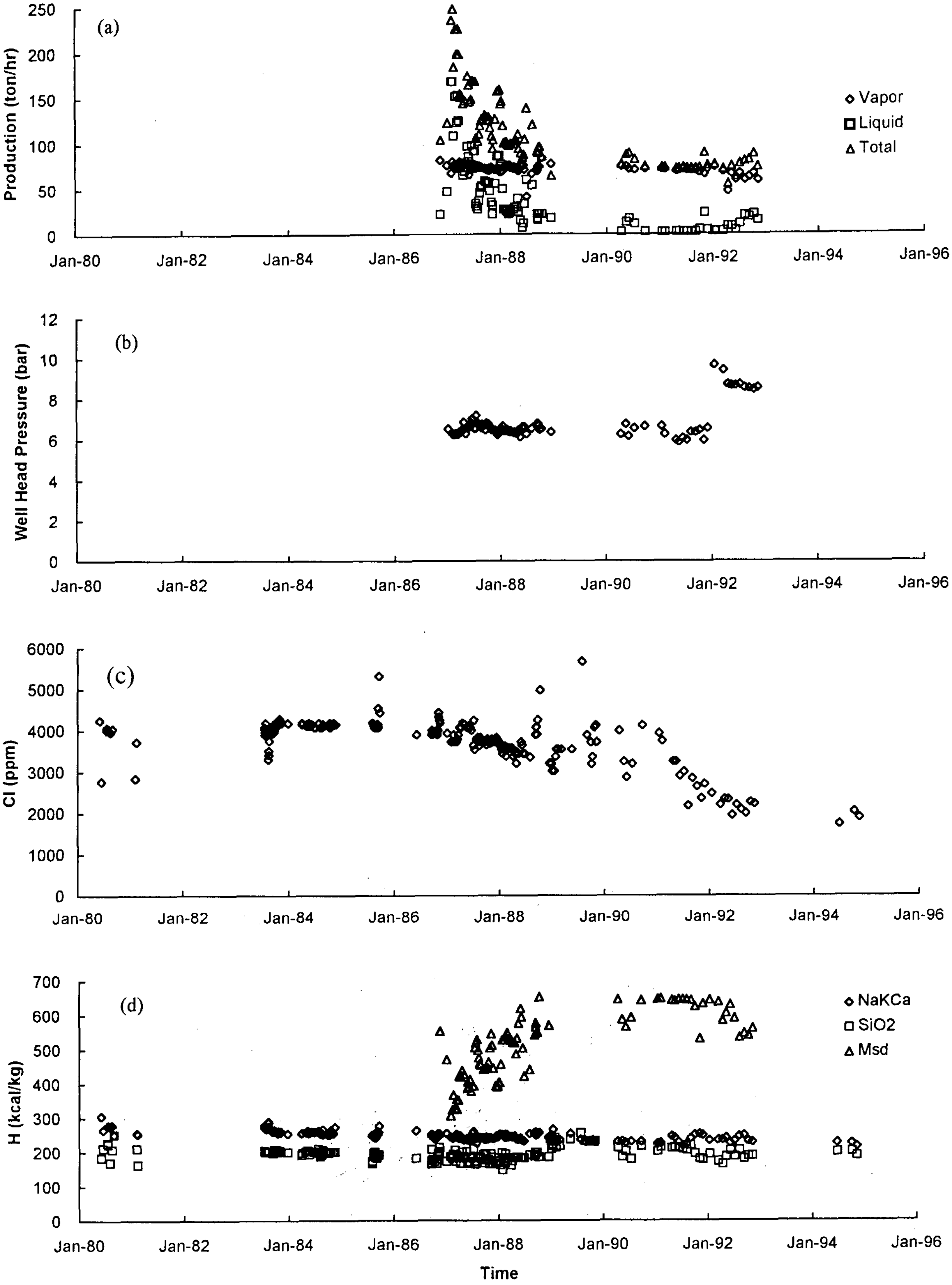

Figure 2: The production and chemical characteristics of the geothermal fluid of well Mt-12.

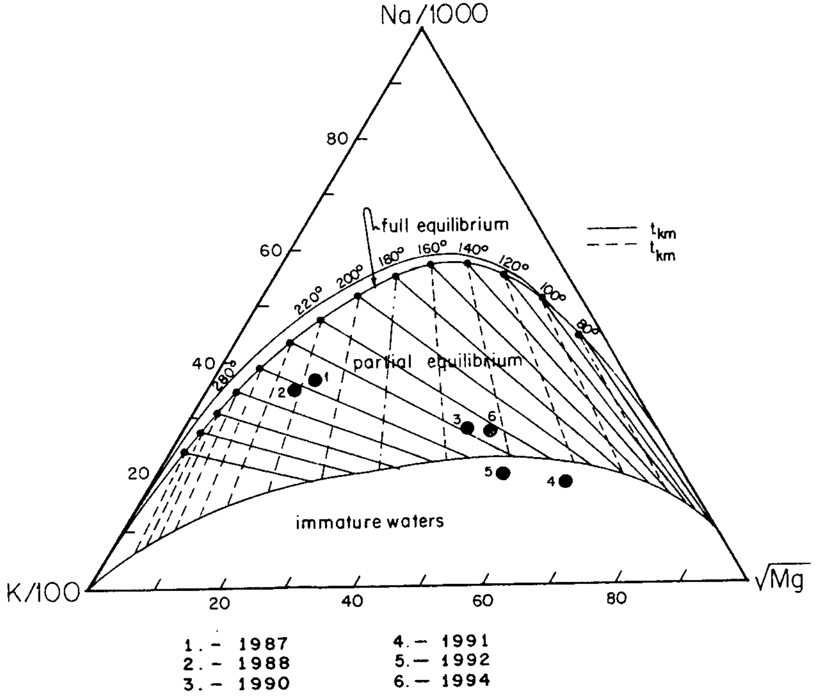

Figure 3: A triangular diagram of relative contents of Na^+, K^+ and Mg^{2+} in the fluid from well Mt-12.

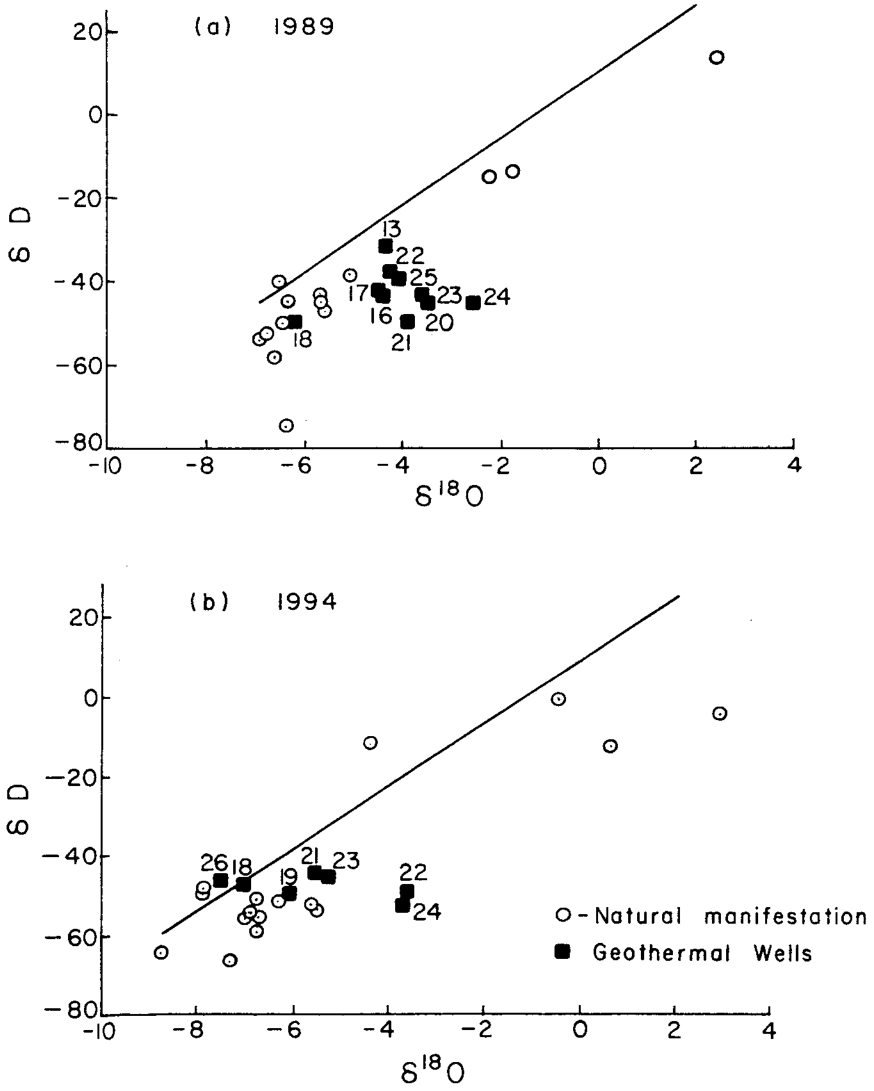

Figure 4: Isotopic relation of the fluid from the Momotombo geothermal field.