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CHEMICAL AND ISOTOPIC STUDIES IN THE MIRAVALLES GEOTHERMAL FIELD COSTA RICA

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ABSTRACT

Commercial generation in the Miravalles geothermal field began in 1994 with the installation of a 55 MW condensing power plant, and at present, the total generation is about 117 MWe. The reservoir fluids have a sodium-chloride composition with a TDS of 5500-6000 ppm, a neutral to slightly alkaline pH, and temperatures around 230-240 °C. According to isotopic measurements, the recharge zone is located in the northern part of the Miravalles area. During the five years of exploitation, the bicarbonate, sulphate and chloride spring waters (i.e. San Bernardo, Las Hornillas and Salitral Bagaces) present a constant isotopic composition. The majority of the well waters show significant increases in heavy isotopes when comparing the pre-1997 to the 1997 data, whereas very little change is observed between the 1997 and 1998 data. In most of the wells, minor chemical changes can be detected in the production fluids with time, mainly in the chloride content. Contour maps show two trends of mixing of deeper fluid with the reinjection water.

1. INTRODUCTION

The Miravalles geothermal field is located in the north-western part of Costa Rica, in the Guanacaste Province. The field is developed to the south and south-west of the Miravalles Volcano, one of the principal volcanoes of the Guanacaste Mountain Range. This range represents an interoceanic volcanic arc developed as a result of the subduction of the Cocos Plate under the Caribbean Plate along the Middle American Trench.

The Miravalles geothermal field is an active hydrothermal area confined to a caldera-type collapse structure with a diameter of 15 km. The caldera was formed about 600 000 years ago with the eruption and deposition of pyroclastic flows. Collapse of the caldera by over 1000 m has been estimated (ICE/ELC, 1986).

The Miravalles geothermal field is a typical high-temperature liquid dominated reservoir. It is encountered at about 700 m depth. Reservoir temperatures decline towards the south and west (Vallejos, 1996). Numerical simulations and reservoir monitoring show that the operation of both the first and second units will not exhaust the potential resources of the geothermal field (GeothermEx, 1998).

The fluid discharged by Miravalles wells is sodium chloride rich (78-80 %), with total dissolved solids (TDS) about 7000-8000 ppm, pH about 8, and silica content around 550-650 ppm at atmospheric pressure. This water has closely approached equilibrium with the alteration minerals (Panichi, 1997). Wells PGM-02, PGM-06, PGM-07 and PGM-19 located in the north east area of the field, discharge water with pH around 2-4 and with high sulphate concentration.

The non-condensable gas (NCG) content has been estimated from 0,6 to 0,9 % weight of steam. The NCG is composed mainly of CO_2 (97-99 % w), with relatively high N_2 content (1,4 to 2 % w) and low H2S content (<1% w).

Isotopic studies suggest that the recharge zone is located in the northern part of the Miravalles area, with an isotopic composition of -25 $^0/_{00}$ and -4,5 $^0/_{00}$ for deuterium and oxygen, respectively (Giggenbach and Corrales 1992). The estimated isotopic composition of the deep parent water (DPW) (δD = -25 $^0/_{00}$, $\delta^{18}O$ = -2 $^0/_{00}$) is derived from the recharged water where the oxygen shift is explained by mixing of the recharge water with andesitic water (Giggenbach and Corrales 1992).

The different isotopic compositions observed for the geothermal fluids discharged from the wells has been explained by mixing between the DPW and local groundwaters, which are characterised by considerably lighter isotopic values (about -50 $^0/_{00}$ and -7,5 $^0/_{00}$ for deuterium and oxygen, respectively) The purpose of the present study is to compare the isotopic composition of the Miravalles fluids from 1997 with the data from 1998 in order to study changes occurring due to the exploitation of the field.

2. CHEMICAL AND ISOTOPE COMPOSITIONS OF THE MIRAVALLES FLUIDS

2.1 Sampling.

Most of the chemical data for the wells used in this report were collected in weirbox, during the years 94-98. The gas samples were collected at the same time but at different pressures. In order to make data files to run the Watch computer program (Arnórsson et al., 1982; Bjarnason,1994), the gases in the steam were recalculated to the collection pressure of the water samples (mainly atmospheric pressure).

Collection of water samples from rivers, hot and cold springs and wells for isotope and chemical analysis for this project was conducted during 1997 and 1998. The chemical analysis were made by ICE and the isotopic analysis by IAEA, Vienna Austria.

2.2 Thermal fluids.

In order to classify the waters, the main anions of the springs (hot and cold) and the wells sampled for the IAEA project COS/8/008 are plotted in Figure 1.

The figure shows that most of the springs are found between the bicarbonate and sulphate corners. The samples close to the bicarbonate corner are located in the centre and towards the south of the field, and represent waters with high CO_2

reactivities at the periphery of the Miravalles geothermal field.

Samples nearer to the sulphate corner are on the other hand located in the northwestern part of the well field, between Guayabal, Los Llanos and Sitio Las Mesas, on the slope of the Miravalles Volcano. Three of them have low pH (1.78-2.83), and one of these springs, Guayabal spring (N-17), also has a high concentration of chloride. It is probably of volcanic origin, but is considerably diluted due to mixing with meteoric water during its rise to the surface. The other two samples (N-15, N-19) have lower chloride concentrations, and are probably of meteoric water origin, heated by steam. The rest of the samples (N-18, N-16) have neutral pH and very low conductivity and TDS and represent the local meteoric water.

Most of the chloride waters are discharged from deep wells and only one chloride spring was found. It is located in Salitral Bagaces (N-13) in the southern part of the area under study, about 19,5 km from the summit of the Miravalles Volcano and at the elevation of 170 meters above sea level (m.a.s.l.). This travertine depositing spring is characterised by high TDS, chloride concentration and conductivity, with a temperature of 54 °C. It is considered to be the outflow of the reservoir, which, due to the topographic restrictions, has travelled over a long distance.

In Figure 1 a mixing line between fluids of the wells with local groundwater is indicated. The water discharged at Salitral Bagaces (N-13) shows high ratio of deep water, whereas the water discharged at San Bernardo Abajo (N-10) and Salitral 2 (N-12) is probably formed when the Cl-rich water moving toward Salitral Bagaces mixes with local groundwater.

These chemical results above are very similar to the results obtained by Giggenbach and Corrales (1992).

2.3 Isotopic composition

Isotopic variations occur in natural systems (gas-water-rock assemblages) as a result of the natural processes in the environment. The mean annual isotopic composition of precipitation is related to the mean annual temperature and is affected by altitude, latitude and continental effects. The lower the temperature, the lower the content of heavy isotopes. At higher altitude and latitude the rainfalls are isotopically lighter than in the lowlands. Deuterium is used as natural tracer to locate the recharge area of the groundwater system and to study their flow patterns. The isotopic analyses of water samples from springs and wells gives information about the origin of the field discharges, their age and possible underground mixing processes between different waters, about water-rock interaction and about steam separation processes (Nuti, 1991).

In Figure 2 the 1997 and 1998 data for the Miravalles fluids is shown on a standard δD vs δ^{18}O plot. Waters from rivers and cold springs define the local meteoric line showing a linear correlation with a slope of 8.42 and deuterium excess of 12.98, which is close to the meteoric water line defined by Craig (1961). The variations in the isotopic contents of the precipitation in the Miravalles area appear to be a function of the geographic distribution rather than due to the normal altitude effect (Panichi, 1997). This is explained by the fact that the Guanacaste Cordillera is affected by precipitation originating both from the Atlantic and Pacific oceans.

Also shown on figure 2 is the isotopic composition of the deep parent water (PW) as defined by Giggenbach and Corrales (1992).

The chemical and isotopic compositions of the hot and cold springs seem not to be affected by the exploitation of the reservoir, as the 1997 and 1998 data give almost the same values (Table 1a). Only the Catarata (N-08) and Hornillas (N-19) samples show different chemical and isotopic composition between the years 1997 to 1998.

In Figure 2 three trend lines are indicated. One of these trends shows the oxygen shift between the meteoric line and the deep parent water. According to Giggenbach and Corrales (1992), the deuterium content of the meteoric recharge to the reservoir is the same as for the parent water (-25 $^0/_{00}$). Such waters are found within the northern part of the field thus defining the recharge area. The second trend shows the mixing line of the groundwater found inside the caldera with the deep parent water. The water discharges of the wells sit on this mixing line, close to the parent water end. The last trend shows a mixing line between the deep water, Salitral Bagaces and groundwater derived from the south. This trend was also suggested on Figure 1.

Figure 3 represents the relationship of the δD and δ^{18}O against the chloride concentration for cold and hot springs, and wells collected for this project. The production boreholes plot close to each other, within the range from -2,18 to -3,27 for δ^{18}O and from 2932 ppm to 3220 ppm in chloride content. The range for the cold and hot springs is from 1,02 to -7,97 for δ^{18}O and from 2 to 178 ppm in chloride concentration except for the Salitral Bagaces spring (N-13) (2674 ppm) which is similar to the wells and the Guayabal spring (N-17)(703 ppm). Both springs discharge water likely to be a mixture of the deeper fluid and local meteoric water as indicated in Figure 2. The mixing lines shown on Figure 2 are also shown on Figure 3.

3. SPATIAL VARIATIONS

The chemical and isotopic data from the wells and the measured enthalpy have been contoured on maps in order to study the chemical and thermodynamic properties of the Miravalles field with time and space.

On Figure 4 a comparison is made between the enthalpy distribution measured in 1994 and 1998.

The figure shows that the enthalpy distribution in the early exploitation months (1994) is smooth, and relatively little scattering is observed in the enthalpy values (1000-1130 kJ/kg). The higher values around 1100 kJ/kg were measured in the northern wells (PGM-11, PGM-10, PGM-01, and PGM-05), and the lower enthalpies around 1000 kJ/kg were found in the southern part of the production area.

The line of 1050 kJ/kg is enhanced on both maps in order to see easily the changes within the production zone. The 1998 enthalpy values are very similar to the 1994 values; however, some trends can be observed. One of these is a clear tendency towards increased enthalpies shown by wells from the centre production field to the south-east (PGM-03, PGM-46, PGM-21, and slightly PGM-17). This likely reflects development of a two-phase (boiling) system. Two trends towards decreasing enthalpies are also observed: one in the north, close to well PGM-05, and the other in the south, close to well PGM-12. This is likely to be caused by reinjection of wastewater into wells PGM-22 and PGM-24.

A comparison is made between the reservoir chloride contours from 1994 and 1998 on Figure 5.

The reservoir chloride distribution in the first year of exploitation shows a smooth distribution, like the enthalpy contours, with values ranging between 2800 and 3011 ppm, and with the maximum values in the eastern part of the production field and the lowest chlorine contents in the northern and western part of the field. The 3000-ppm contour line is enhanced on both maps in order to recognise easily the changes within the production zone. The 1998 reservoir chloride concentration is considerably different in some wells from the 1994 values (about 200 ppm), whereas other wells show almost constant values. In the 1998 map, two trends towards increasing chloride content are indicated: one in the north, close to wells PGM-05 and PGM-10, and the other in the south, near well PGM-12. Wells PGM-03, PGM-46, PGM-21,and PGM-17 show also a slight tendency to increase.

4. ISOTOPIC CHANGE WITH TIME

The stable isotopes in the waters are a useful tool to monitor possible changes in the reservoir because the geothermal waters, the reinjection water and the local ground waters have different isotopic compositions.

In order to examine closely the scale of data from the geothermal wells, the δD vs $\delta^{18}O$ plot is expanded on Figure 6. Although the wells are close to each other, there are apparently two trends. An apparent enrichment trend is shown from production wells toward reinjection well PGM-24, and an apparent isotopic depletion is shown only for well PGM-21. This depletion is likely caused by mixing with isotopically lighter water, but this should be confirmed by more careful chemical and isotopic monitoring.

Isotopic compositions of the 1998 samples from wells PGM-01, PGM-22, PGM-16 and the 1997 sample from well PGM-20 are difficult to explain with regards to the other isotopic data from the area (see Figure 2 and 3).

5. DISCUSSION

After some time, exploitation of a geothermal field usually produces a pressure drop in the reservoir (drawdown) as a natural consequence of fluid and energy extraction. The drawdown or pressure drops can produce serious problems due to the potential danger of inflow of cold groundwater or reinjection water followed by reservoir cooling and changes in the production characteristics of the wells. Usually the changes in the chemical composition of the fluids (chemical front) is observed before the thermal front arrives into the well. Hence chemical monitoring of the fluids may give a warning in time for preventative action. The measurements of the flow-rate, pressure and temperature of the wells should be made at least once a year. If these measurements are too expensive to be performed so frequently, the chemical monitoring should be expanded to replace the direct measurements. However, both monitoring programs are necessary in order to get a good understanding of the processes taking place in the reservoir and to optimise the production parameters for each well. Chemical monitoring programs have been developed for different types of geothermal fields but the interpretative power is enhanced by combining data from both chemical and isotopic monitoring. The effectiveness has been demonstrated in both high-temperature and low-temperature geothermal exploitation (Kristmannsdóttir and Ármannsson, 1996).

Most of the reservoir parameters have been affected by the exploitation of the Miravalles field according to this study. Wells PGM-17 and PGM-11 are the most stable boreholes; at present, only the enthalpy shows a slight change possibly due to measurement uncertainties. In general the enthalpy in the early years of exploitation (1994-1996) increases in most of the wells with time. The enthalpy increase is a normal process in most high-temperature liquid dominated reservoirs. It is caused by the development of two phases (boiling) in the reservoir, mainly in the shallow aquifers as a consequence of the drawdown produced by the fluid extraction. The enthalpy usually decreases when the reservoir is affected by inflow of cold fluids. These fluids could be cold groundwater or reinjected geothermal water. Groundwater usually is characterised by high content of magnesium, low concentration of chlorine and TDS. The reinjection water, on the other hand, usually has high chlorine content and TDS and low magnesium concentration. Most of the wells show a tendency towards increased reservoir chloride content with time. This is probably caused by boiling within the aquifer. The greatest increment shown in wells PGM-05 and PGM-12 is however due to the arrival of the reinjection water into these wells. Contour maps for chemical parameters show the effects caused by the reinjection, in the north (PGM-05) and in the south (PGM-12).

The chemical and isotopic compositions of the hot and cold springs in the Miravalles field seem not to be affected by the exploitation of the reservoir (Table 1, Appendix). The isotopic composition of the fluid discharged by Miravalles wells in 1997 and 1998 are almost identical. The δD range for the 1997 samples is -28,6 to -30,2; and for the 1998 samples is -28,1 to -33,2. The $\delta^{18}O$ range for 1997 is from -2,69 to-3,1; and for 1998 samples is from -2,61 to -3,10. The 1997 value for well PGM-20 and the 1998 values for well PGM-01 are not included in this comparison because they are anomalous in their deuterium content. PGM-21 shows a slight indication of mixing with groundwater when the 1997 sample is compared to the 1998 sample, but the change is only 3 per mil in δD and 0.2 units in $\delta^{18}O$.

Only two samples show substantial differences in isotopic composition between the years 1997 and 1998. They are Catarata and Hornillas. Catarata is a waterfall in the northern part of the field at 1270 masl and is characterised by very low conductivity and TDS. The difference in isotopic composition between data from 1997 (δD = -23,9 and $\delta^{18}O$ = - 4,62) and 1998 (δD = -15,7 and $\delta^{18}O$ = -3,56) is likely to be caused by the fact that the 1997 sample was taken during the rainy season whereas the 1998 sample was taken during the dry season. The latter sample is probably more affected by evaporation than the 1997 sample due the season effect (different temperatures). Hornillas is a geothermal manifestation in the north of the field, characterised by the presence of fumaroles, steam heated pool and steaming ground. The difference in isotopic composition between 1997 (δD = -0,3 and $\delta^{18}O$ = 1,02) and 1998 (δD = -17,8 and

$\delta^{18}O$ = -2,60) data suggests that the 1997 sample is more affected by evaporation than the 1998 sample.

The heaviest sample of the 1998 data is from well PGM-24. This well is used for hot reinjection and the isotopic composition of this fluid reflects the effect of boiling (steam separation).

According to Giggenbach and Corrales (1992) the deuterium content of the meteoric recharge of the Miravalles reservoir is the same as for the parent water ($-25\ ^{0}/_{00}$). Such waters (2 samples) are found within the northern part of the field thus defining the recharge area .

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main results of this study can be summarised as follows:

1. At present the chemical and isotopic compositions of the hot and cold springs are not affected by the exploitation of the Miravalles reservoir.
2. Only minor changes can be detected in the isotopic composition of the discharging fluids from wells between the years 1997 and 1998.
3. The recharge area is within the northern part of the field.
4. Wells PGM-17 and PGM-11 are chemically and physically the most stable boreholes at present.
5. Most of the wells show a tendency towards increased reservoir chloride content. The greatest increment is shown in wells PGM-05 and PGM-12.
6. The reinjection water is detected in the north and in the south of the production zone, and reinjection probably affects the temperature of wells located in these areas.
7. The chemical trends detected in this study will probably become larger when fluid production increases as the second condensing unit starts production.

9.2 Recommendations

When the second unit starts:

1. The measurements of the flow rate, pressure and temperature for each well should be made at least once a year, mainly in the wells located in the areas affected by the reinjection fluids in order to detect or confirm changes in the reservoir
2. At least three monitoring wells should be located in the production zone in order to detect the changes in the pressure due to exploitation. One monitoring well should be located in the reinjection zone in order to monitor the effect of the wastewater injection.
3. The chemical monitoring program should be expanded from once to three times per year and one of the three samplings should coincide with the measurements of physical parameters.
4. The stable isotope monitoring should be incorporated into the program in order to detect or confirm changes in the reservoir and should be made at least once a year.
5. Tracer tests should be carried out in wells PGM-22 and PGM-24 if these wells continue to be used for reinjection. The purpose of the tests is to study fracture connections between these wells and the production wells and to estimate the amount of reinjected water showing up in the production wells. When the tracer is injected into well PGM-22, wells PGM-05, PGM-10, PGM-08 and PGM-42 should be monitored, and when the tracer is injected into well PGM-24, wells PGM-12, PGM-20, PGM-46, PGM-49 should be monitored.
6. A tracer test should be carried out in the southern part of the well field in order to define the effect of the reinjection water there. The tracer injected in well PGM-29 or PGM-28 and tracer returns monitored in wells PGM-21, PGM-12 and PGM-46.
7. A tracer test is also recommended if well PGM-04 is still to be used for continuous injection. The objective of this test is to study the connection between well PGM-04 and the production wells PGM-20 and PGM-12.
8. In order to confirm that the recharge water is located in the northern part of the field, it is recommended to do more chemical and isotopic study of this area.
9. The measurements of the injectivity index for each reinjection well should be made at least once a year.

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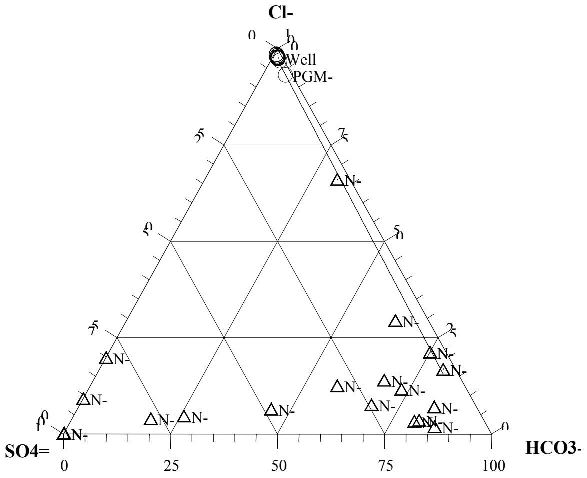

FIGURE 1 Cl-SO4-HCO3 Triangular diagram

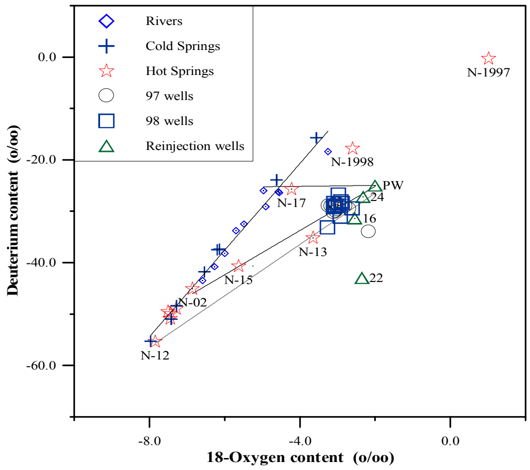

Figure 2: Isotopic composition of waters from the Miravalles Geothermal field 1997-1998

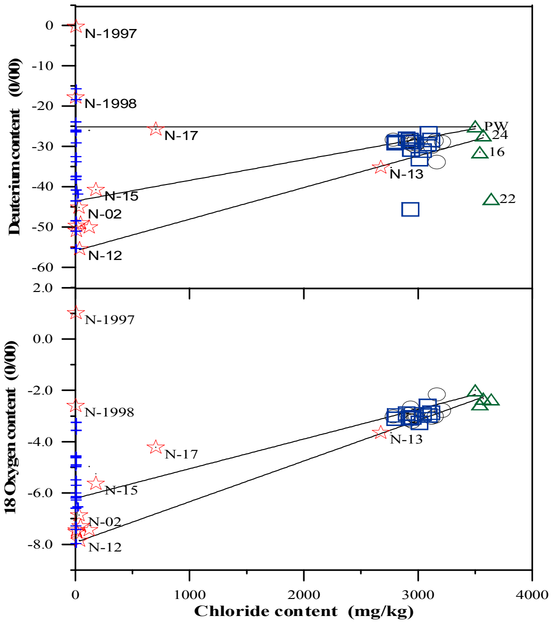

Figure 3 : Deuterium and 18 Oxygen vs Chloride

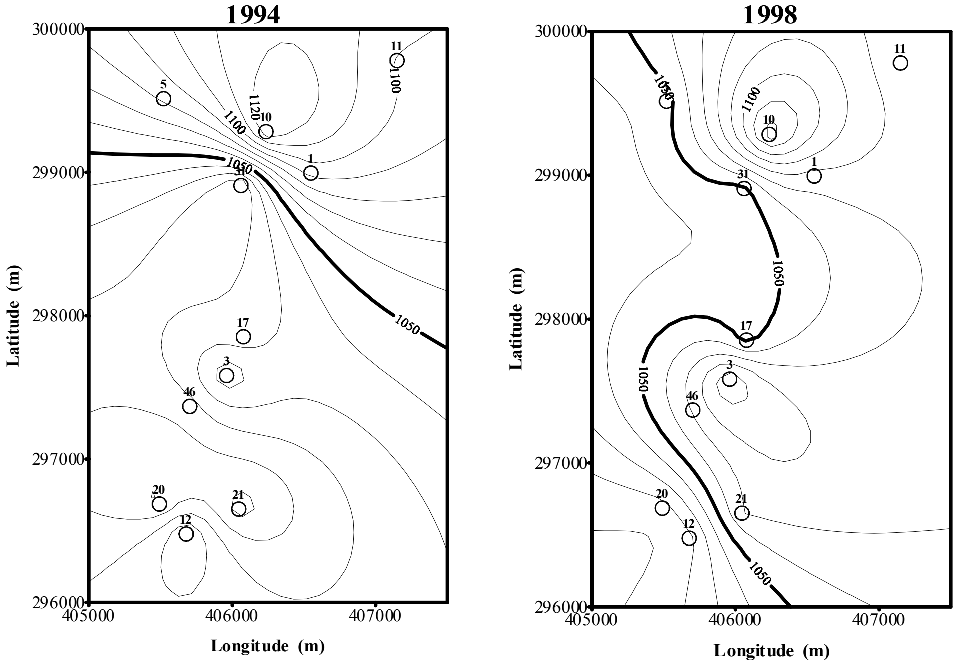

Figure: 4 Enthalpy contour 1994-1998, Miravalles geothermal field

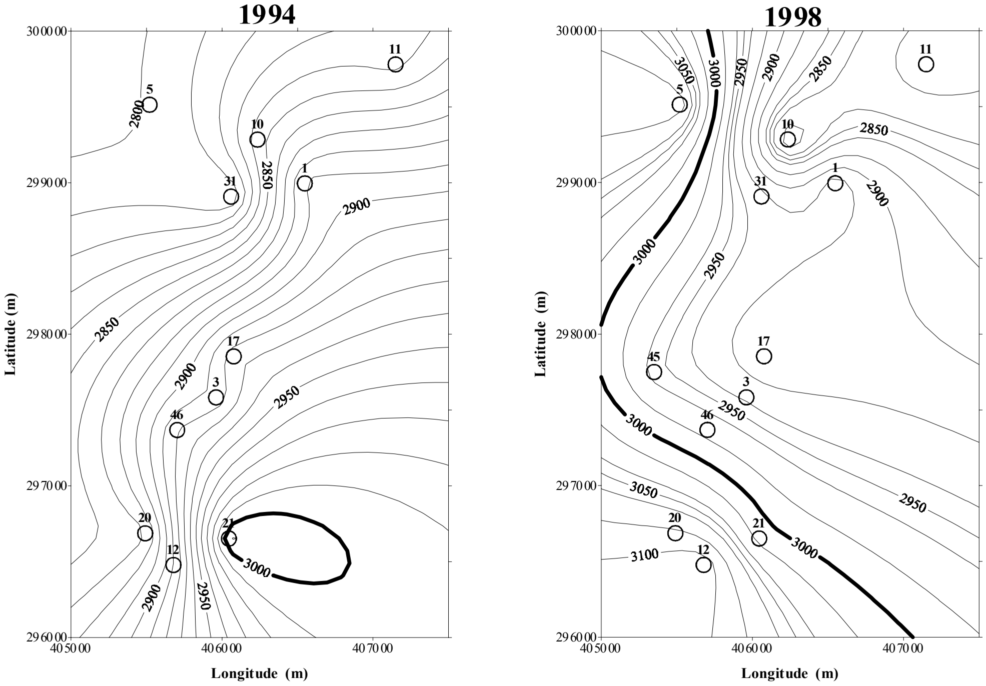

FIGURE: 5 Reservoir chloride distribution 1994-1998, Miravalles geothermal field

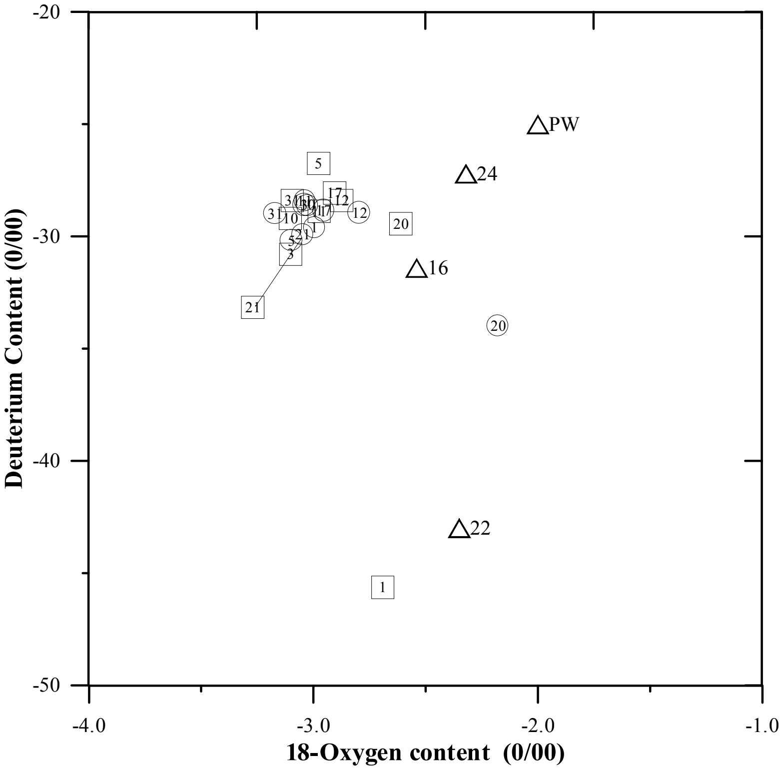

FIGURE: 6 Isotopic composition of Miravalles wells 1997-1998