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CHEMICAL AND ISOTOPIC STUDIES IN THE MIRAVALLES GEOTHERMAL FIELD, COSTA RICA

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ABSTRACT

Commercial electric generation in the Miravalles geothermal field started in 1994 with installation of a 55 MW condensing power plant and at present the total generation is about 70 MWe. The reservoir fluids have a sodium-chloride composition with total dissolved solids 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. Over four years of exploitation the bicarbonate, sulphate and chloride spring waters (i.e. San Bernardo, Las Hornillas and Salitral Bagaces) present a constant isotopic composition, while the majority of the well waters shows a significant increase in heavy isotopes when comparing the pre-1997 data to the 1997 data, while 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 chloride content. Contour maps show two trends of mixing of deeper fluid with reinjection water. These trends should become more pronounced when a second unit of the power-plant starts to operate in September 1998. Evaluation of the saturation index with respect to chrysotile, talc and calcite suggests that the deep water is slightly undersaturated with respect to chrysotile and talc and slightly over-saturated with respect to calcite. After adiabatic boiling the fluid becomes over-saturated with respect to these minerals leading to a higher scaling potential. Calcite supersaturation has decreased with time.

1. INTRODUCTION

After almost 20 years of geothermal exploration in Costa Rica, the first 55 MWe unit of the Miravalles geothermal field was commissioned in March 1994, and in November of the same year a 5 MWe back pressure power plant was added (ICE/ELC, 1995). In 1995 the main power plant was upgraded to produce 60 MWe. Two back pressure units of 5 MWe each were installed in 1996, but in March 1998 one of them was dismantled. The second 55 MWe condensing power plant construction has been completed and it is expected to be commissioned in September 1998. This will bring total power generation to 125 MWe. The third unit of 27.5 MWe capacity is planned for year 2000 and by that time the total power generated from geothermal energy will be 147.5 MWe (as one of the back pressure units

will be dismantled by that time).

The Miravalles geothermal system is a typical high-temperature liquid-dominated reservoir. It is encountered at about 700 m depth, with reservoir temperatures declining to the south and west (Vallejos, 1996). Numerical simulations and reservoir monitoring show that the operation of the two units will not exhaust the potential resources of the geothermal field.

Most of the fluids discharged by Miravalles wells are 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-07 and PGM-19 discharge water with pH in the range of 2-4 and with high sulfate concentration. According to Panichi (1997) this water may have formed by dissolution of HCl and SO_2 from the magma heat source. The third water type is steam-heated water, which is discharged from the warm low-chloride springs in the gorge of Río Blanco.

The non-condensible gas content (NCG) has been determined from 0,6 to 0,9% weight of the steam. It is composed mainly of CO_2 (97-99% w), with relatively high N_2 content (1,4-2% w) and low H_2S content (<1% w).

Isotopic studies suggest that the recharge zone is located in the northern part of the Miravalles area, with isotopic composition of -25‰ and -4,5‰ (Smow) for deuterium and oxygen-18, respectively (Giggenbach and Corrales, 1992). The estimated isotopic composition of the deep parent water (DPW) (δD = -25‰, $\delta^{18}O$ = -2‰) is derived from the recharged water where the oxygen shift is explained by the mixing of recharge water with andesitic water (Giggenbach and Corrales, 1992). The different isotopic composition observed for the geothermal fluids discharged from the wells has been explained by mixing between the deep parent water and local groundwaters, which are characterized by considerably lighter isotopic values (about -50‰ and -7,5‰ (smow) for deuterium and oxygen-18, respectively).

All geothermal fluids coming from Miravalles wells form calcite scaling. The carbonate deposition occurs mainly in the flashing zone within the borehole, and it causes a fast flow rate and a decrease in potency. An inhibition system is used in Miravalles in order to avoid calcite scaling. The scale inhibitor is pumped through a small injection tube and is discharged below the boiling zone.

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 exploitation of the field. A second objective is to obtain a better understanding of the reservoir processes through a simultaneous study of the isotopic data, and the physical and chemical monitoring data in order to get a good chemical and isotopic database for the reservoir before operation of the second 55 MWe unit starts.

2. MIRAVALLES GEOTHERMAL FIELD

2.1 Location

The Miravalles geothermal field is located in the northwestern part of Costa Rica, in the Guanacaste Province (Figure 1). The field is developed to the south and southwest of the Miravalles Volcano, one of the principal volcanoes of the Guanacaste Mountain Range. The elevation of the field is between 400 and 800 m a.s.l. with an average gradient of 5%. The field is located 150 km northwest of San José, the capital of Costa Rica; the nearest commercial airport is located 60 km west of the field and the nearest commercial port 120 km southwest of the field.

2.2 Geologic - tectonic setting

2.2.1 Regional setting

The Guanacaste mountain 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 which is formed by the subduction process along the Central American Pacific coast between Mexico and Costa Rica. The subduction zone is bounded by the Polochic and Motagua faults in the north and in the south by the Cocos ridge and the Panama fault zone (Figure 2).

The Nicoya ophiolite complex, which consists of peridotites of Cretaceous age lies between the Middle American Trench and the Guanacaste Cordillera. These are covered by up to 5000 m of Upper Cretaceous to Miocene marine sedimentary rocks, mainly silt- and sandstones.

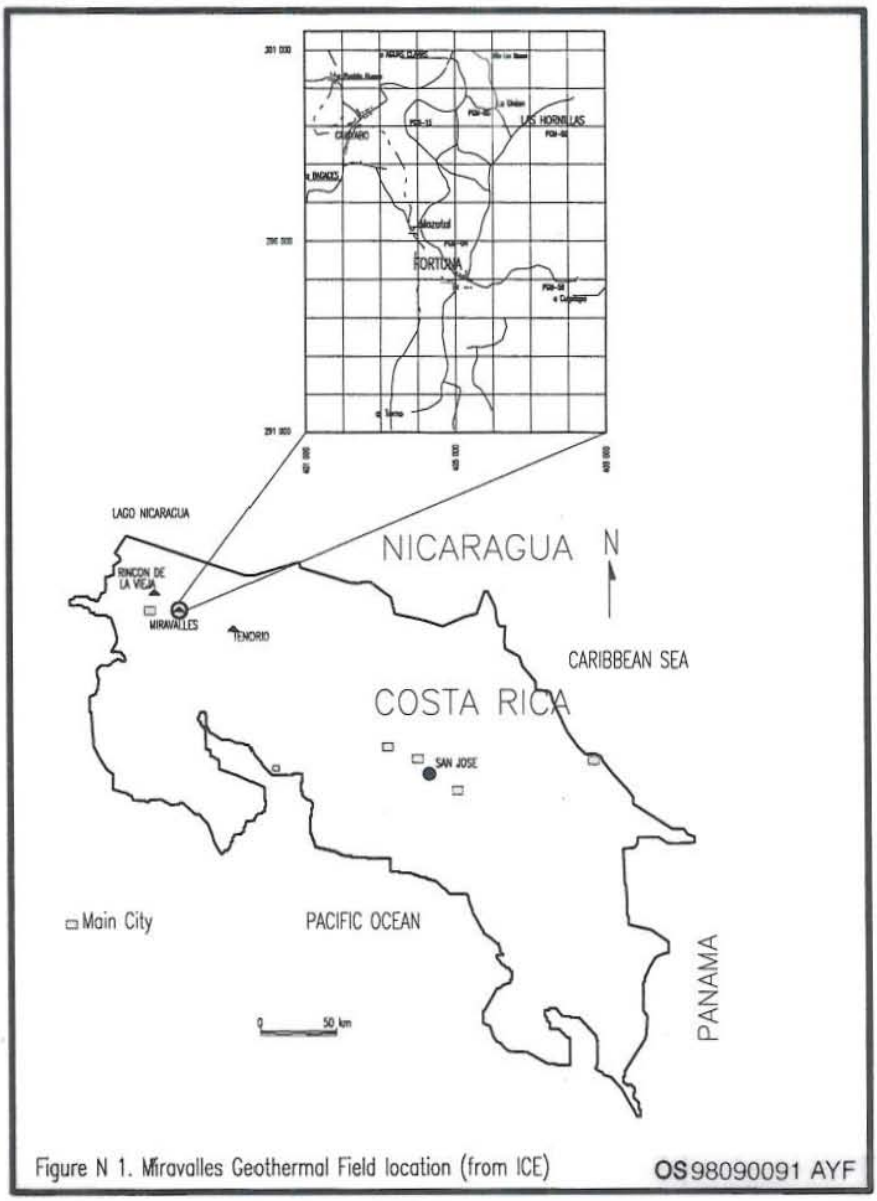

FIGURE 1: The location of the Miravalles geothermal field

The Guanacaste volcanic arc comprises Tertiary and Quaternary volcanic rocks. The Tertiary complexes appear as a plateau of andesites with abundant pyroclastics and ignimbrites intercalated with detrital sediments. The Quaternary rocks are predominantly lavas related to the large stratovolcanoes aligned along a NW-SE trend. The principal volcanic complexes are Orosi-Cacao, Rincón de la Vieja-Santa María, Miravalles-Paleo Miravalles and Tenorio-Montezuma. (Figure 1). These are characterized by andesitic compositions and the presence of tuffaceous deposits, ignimbrites and lahars towards the base. The outer basin of the arc is occupied by alluvial deposits and Quaternary lahar derived from the Cordillera, Tertiary plateau volcanics and small volcanic edifices (ICE/ELC, 1986).

2.2.2 Local setting

The Miravalles geothermal field is an active hydrothermal area confined to a caldera-type collapse structure (Figure 3) with a 15 km diameter. The caldera was formed about 600,000 years ago with the

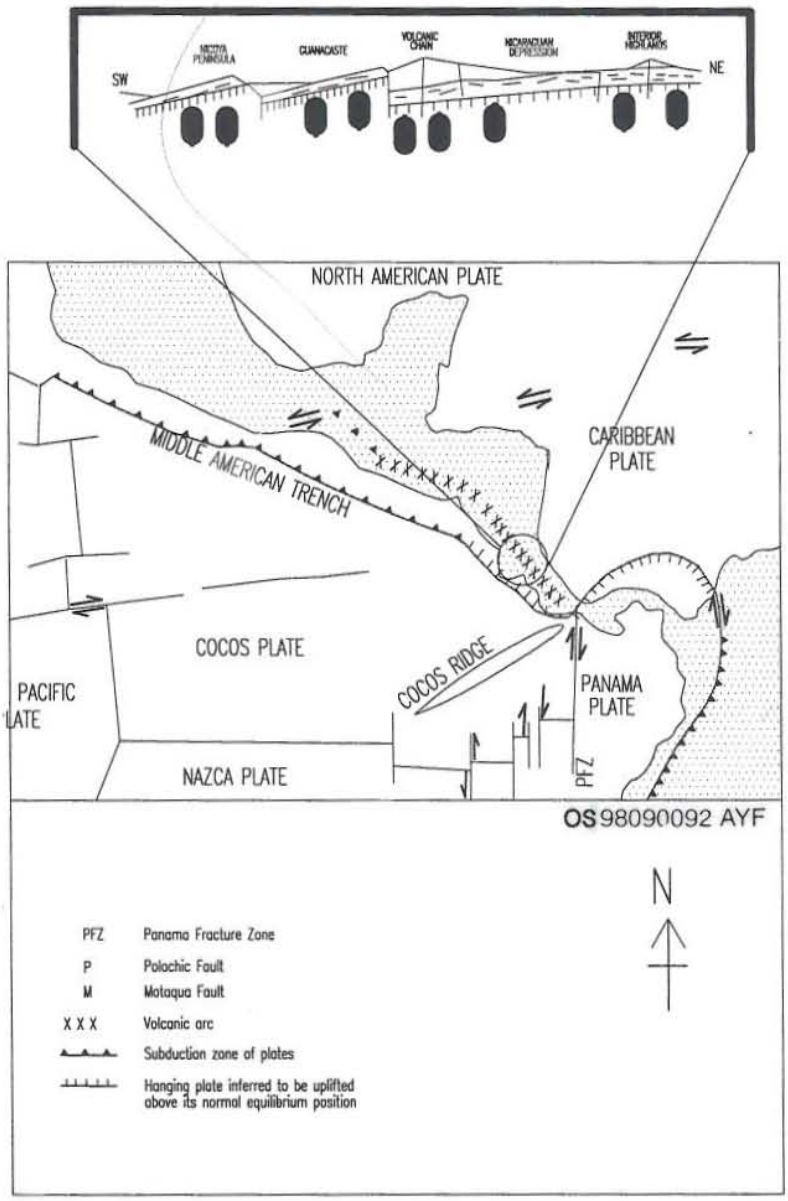

FIGURE 2: Sketch of the subduction zone, where the Cocos plate goes under the Caribbean plate

swarm with an E-W trending fault (ICE/ELC, 1986).

eruption and deposition of pyroclastic flows. A collapse of the caldera by more than 1000 m has been estimated (ICE/ELC, 1986). In association with, or soon after the caldera formation, a sub-vertical fracturing striking N-S, to WNW-ESE direction towards the east of the caldera occurred. This gave rise to a graben which extends southwards beyond the caldera margin (graben La Fortuna).

During the 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.

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

2.2.3 Lithostratigraphic units

According to the geological stratigraphy of the deep wells studied by ICE, the following units have been identified:

Lava basement: Only present in PGM-15, occurs as basement and consists of pyroxene porphyritic-andesites.
Ignimbritic unit: Consists of welded tuff, with a thickness of 1100 m.
Lava tuff unit: Is 300 m thick, consists mainly of intercalated andesitic lavas and crystalline vitric tuffs.
Volcano sedimentary unit: Is 800 m in thickness and consists mostly of alternating lithic tuffs and lutites.

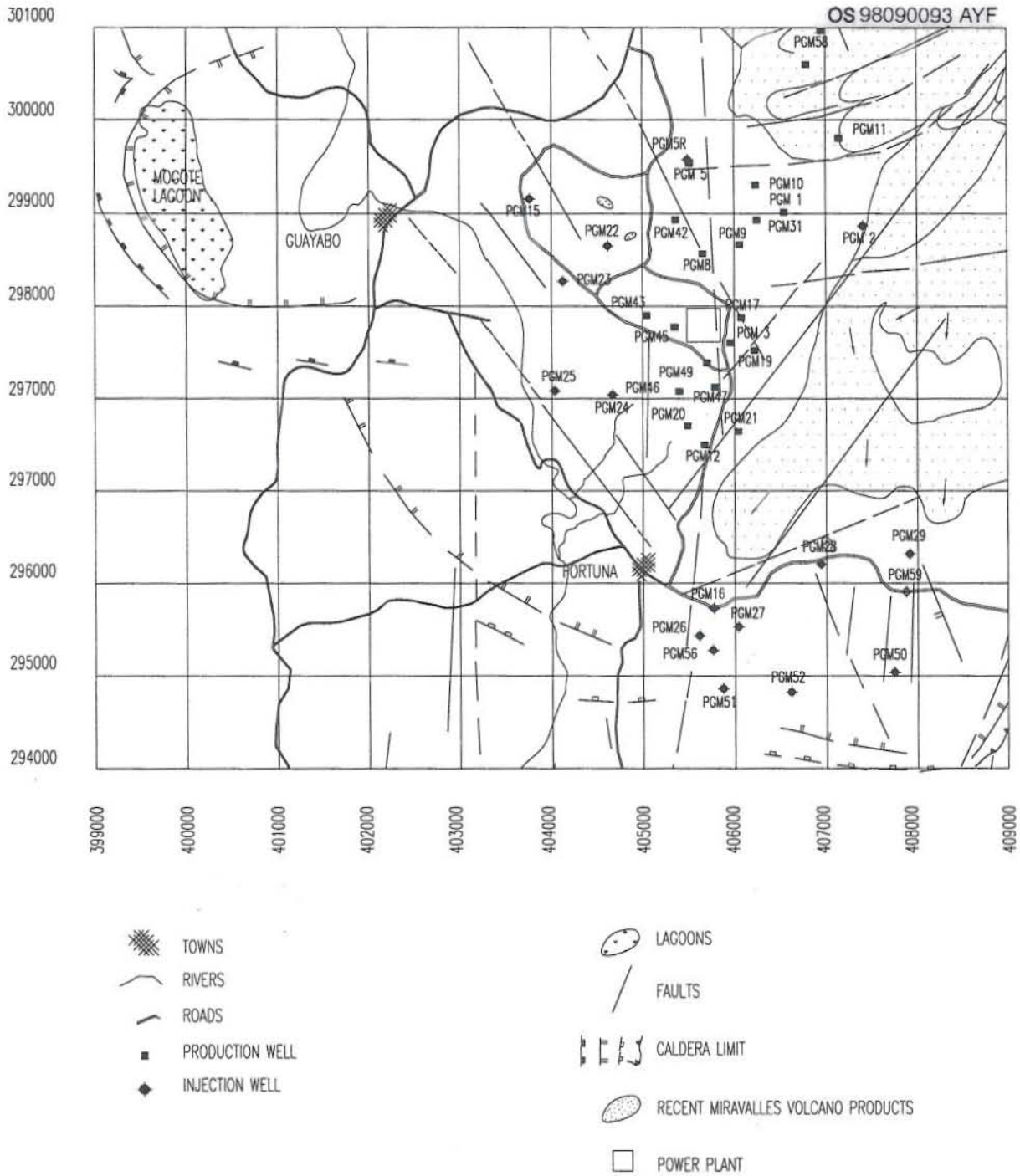

FIGURE 3: The Miravalles geothermal field

Andesite lava unit: Is 900 m thick and composed of andesitic flows.
Cabro Muco unit: Is 400 m thick and consists of andesitic flows with minor tuffs.
Pumice unit: Is 300 m in thickness and consists of pyroclastics and is very rich in pumice.
Vulcanites: Is 300 m thick and consists of explosive products with alternating flows and lahars.

2.3 Production system

The production system used at present comprises mainly thirteen production wells, six steam separators (satellites) and seven injection wells. Eleven production wells are used to feed the condensing power plant (60 MWe) and one the back pressure plants (5 MWe) according to the following design; the two-

phase fluid from the production wells is transported by pipelines to the separation satellites with a maximum steam capacity of 60 kg/s. The steam from the three satellites is carried by separate pipelines or connected pipelines in one collector and the waste water is injected into one or more periphery wells. The separated water transportation is by gravity.

The first satellite receives the two-phase fluid from wells PGM-01, PGM-05, PGM-10, PGM-31 and the steam from well PGM-11. The waste water generated in this unit is injected into well PGM-22 and the steam is sent to the condensing power plant and to the back pressure plant. PGM-11 has a steam separator and the separated water is injected into well PGM-02 which, due to its acidic characteristics, is used as an injection well. The second satellite receives the two-phase fluid from wells PGM-03, PGM-17 and PGM-46. The separated water from this unit is injected into well PGM-24. The third satellite receives the two-phase fluid from wells PGM-20, PGM-12 and PGM-21. The separated water is injected into wells PGM-16 and PGM-26. The second back pressure power plant is fed by well PGM-45 and the waste water is injected into PGM-04 through a cold injection system. The third back pressure power plant is fed by PGM-29 and the waste water is injected into PGM-28.

3. PREVIOUS WORK

A pre-feasibility study in 1975-1976 suggested that a thermal reservoir with temperatures up to 240°C underlies the Miravalles area (Gardner and Corrales, 1977). A typical high-temperature, liquid-dominated reservoir, with sodium chloride waters, relatively low in total dissolved solids (6000 ppm) and with neutral pH was discovered as a result of a feasibility study in the Miravalles area during 1977-1986.

The first isotopic study in the Miravalles geothermal area was carried out in 1982-1987 (Giggenbach and Corrales, 1992). The purpose of this study was to make a hydrological model of the geothermal systems within the Guanacaste geothermal province. This investigation was carried out within the IAEA coordinated research programme on the application of isotopic and chemical techniques to geothermal exploration in Latin America. The main results were:

- The neutral Cl^- water discharged from deep wells is derived from the mixing of deeply circulating groundwater and andesitic waters. The groundwater is of meteoric origin, largely derived from areas to the north of the volcanic chain.

- The isotopic composition of the deep parent water which may represent the isotopic composition of the deep geothermal aquifer was estimated to be δD = -25‰ and $\delta^{18}O$ = -2‰ (smow) and with a chloride concentration of 3500 mg/kg.

- The geothermal fluids were interpreted as the result of mixing between the deep parent water and local groundwaters (isotopically lighter than the meteoric recharge).

- The individual thermal systems (Rincón de la Vieja, Miravalles and Tenorio) are linked at depth to form a large continuous geothermal reservoir beneath the Guanacaste geothermal province.

At the same time two expeditions were made in the Miravalles geothermal area. The first was conducted by Arnórsson in 1986. Thirty nine samples were collected from rivers and creeks for isotopic analysis made by the IAEA laboratory in Vienna, Austria. The second study was made by Los Alamos personnel in 1988, and 23 samples were collected from hot springs and wells for chemical and isotopic analyses made at Alamos Laboratory. The results of both studies were in agreement with those of Giggenbach and Corrales (1992).

In 1989 and 1991 two studies were carried out by ICE-Electroconsult (ELC). The objective of the first

investigation was to evaluate the geothermal potential of Costa Rica. They concluded that the best geothermal areas for electricity generation are located in Rincón de la Vieja, Miravalles and Tenorio. The second study was conducted in the Tenorio area with the purpose to do a pre-feasibility study for that region. A thermal reservoir with temperatures of about 230-240°C was suggested to underlie the Tenorio area.

The last two studies were carried out in 1997 and 1998 under the IAEA technical cooperation project COS/8/008-01 entitled Rational Exploitation of Geothermal Resources. The final report on the first study was presented by Panichi (1997) and the main results were:

- Increase in the concentration of heavy isotopes and chloride was observed in the majority of the productive wells. Two possible explanations were offered, firstly, the increase in exploitation of the field during the last three years may have caused a progressive decrease in the inflow of isotopically light local groundwater. Secondly, the observed changes may be caused by the massive reinjection started in 1994.
- The fluids in wells located in the up-flow zone of the deep fluid are more enriched in ^{18}O than those of other wells.

4. CHEMICAL AND ISOTOPE COMPOSITION OF THE MIRAVALLES FLUIDS

4.1 Sampling

Most of the chemical samples for the wells used in this report were collected from weirboxes, during the years 1994-1998. The gas samples were collected at the same time but at different pressures. In order to make data files to run on 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 the ICE and the isotopic analysis by the IAEA, Vienna Austria.

4.2 Thermal fluids

The results of the chemical analysis, together with the isotopic composition of waters discharged from springs and geothermal wells in the Miravalles area are listed in Tables 1 and 2, respectively. 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 4. The figure shows that most of the spring waters

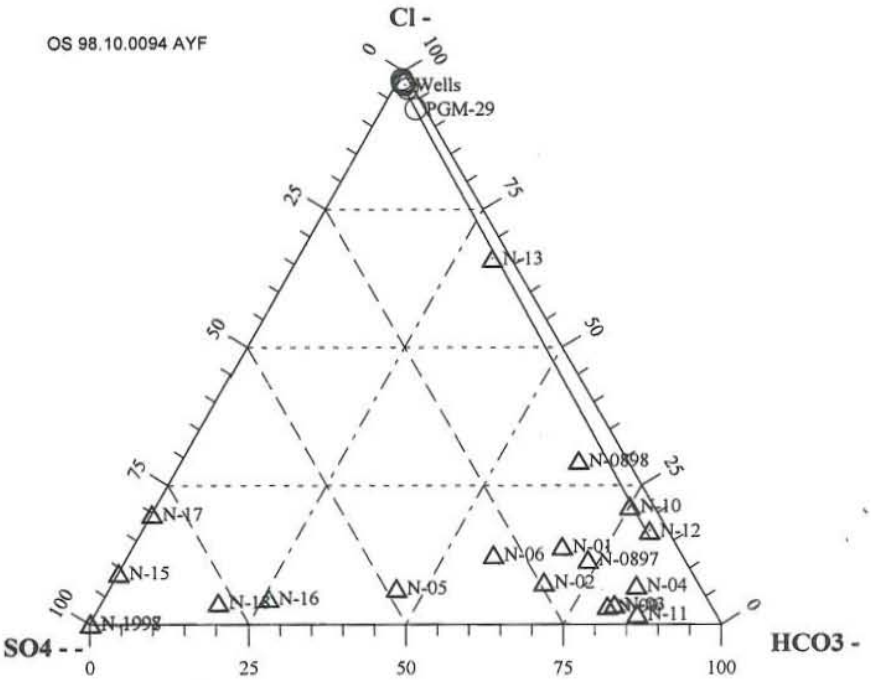

FIGURE 4: Cl-SO_4-HCO_3 triangular diagram for Miravalles waters

TABLE 1: Chemical-isotopic composition of spring waters in ppm, Miravalles geothermal field Costa Rica, 1997-1998

Sample No.	Date	Temp (°C)	pH	Cond. (µS/m)	Na^+	K^+	Ca^{+2}	Mg^{+2}	Cl^-	SO_4^{-2}	HCO_3^-	F^-	B	SiO_2	Ionic bal.	D ‰	^{18}O ‰
N-01	97-98	38	6.75	585	52	16	66	13.8	44	57	214	0.14	0.64	146	9.14	-49.0	-7.29
N-02	97-98	55	6.52	731	54	18	83	20.7	32	102	287	0.17	0.45	188	5.33	-45.1	-6.86
N-03	97-98	37	5.77	372	22	8	46	13.0	8	35	189	0.15	0.16	124	4.62	-50.9	-7.45
N-04	97-98	24	6.64	117	8	2	14	3.0	5	7	62	0.17		78	0.97	-55.3	-7.97
N-05	97-98	23	7.20	157	8	3	20	3.1	5	38	36	0.17		73	4.76	-51.0	-7.42
N-06	97-98	19	6.81	78	6	2	6	1.5	5	12	23	0.38	0.12	50	-3.46	-37.5	-6.25
N-0897	12.6.1997	20	7.66	65	11	2	9	2.3	4	5	26	0.03		30	27.01	-23.9	-4.62
N-0898	15/3/98	16	6.90	22	2	0	4	0.5	6	2	13	0.15		5	-9.11	-15.7	-3.56
N-09	97-98	25	6.18	242	12	4	38	7.5	5	23	115	0.19	0.12	88	11.11	-48.4	-7.28
N-10	97-98	47	6.17	1050	125	22	98	28.4	120	21	423	0.17	1.74	164	10.56	-50.0	-7.44
N-11	97-98	43	6.34	770	56	17	104	36.9	10	62	431	0.27	0.37	151	12.63	-44.7	-7.57
N-12	97-98	43	5.57	387	65	12	13	1.6	35	6	165	0.16	1.10	131	1.63	-55.4	-7.85
N-13	97-98	54	6.67	9835	2134	80	95	5.5	2674	119	1250	0.82	45.00	118	0.84	-37.1	-3.63
N-15	97-98	36	2.83	3345	70	10	507	102.8	178	1741	0	0.13	0.80	120	-5.25	-40.7	-5.63
N-16	97-98	25	5.97	886	34	7	164	36.3	22	324	120	0.37	0.22	101	16.01	-33.9	-6.67
N-17	97-98	62	1.97	7110	56	2	114	18.4	703	2836	0	0.17	1.57	267	-78.05	-25.7	-4.22
N-18	97-98	24	6.51	343	12	3	48	5.6	6	116	28	0.30	1.57	172	6.20	-37.4	-6.14
N-1997	18.6.1997	73	1.78	8110	18	7	32	9.0	5	1882	0	0.02	0.40	367	-84.47	-0.3	1.02
N-1998	16/3/98	86	1.98	6490	18	4	40	4.6	2	1538	0	0.13		288	-81.61	-17.8	-2.60

TABLE 2: Chemical-isotopic composition of well waters in ppm, Miravalles geothermal field, Costa Rica, 1998

Well No.	pH	Na^+	K^+	Ca^{+2}	Mg^{+2}	Al	Fe	Cl^-	SO_4^{-2}	HCO_3^-	F^-	B	SiO_2	NH_3	H_2S	D ‰	^{18}O ‰
PGM-01	5.81	1737	221	51	0.057	0.33	0.03	2933	28	18	1.53	46.24	449	1.27	8.01	-45.6	-2.69
PGM-03	6.34	1764	217	55	0.074	0.37	0.76	2938	31	15	1.46	47.10	440	0.84	4.22	-30.8	-3.10
PGM-05	6.09	1852	225	79	0.104	0.55	0.03	3093	31	12	1.26	47.45	412	1.20	5.38	-26.7	-2.98
PGM-10	5.51	1670	205	63	0.190	0.36	0.11	2799	28	21	1.23	43.07	393	1.13	13.95	-29.2	-3.10
PGM-11	5.75	1694	197	47	0.067	0.28	0.09	2806	32	42	1.19	44.13	450	1.34	10.61	-28.9	-2.97
PGM-12	5.81	1893	228	68	0.103	0.30	0.83	3115	38	2	1.50	49.12	379	1.61	1.75	-28.4	-2.87
PGM-17	5.94	1759	217	52	0.058	0.30	0.07	2900	30	32	1.29	46.89	430	1.83	10.30	-28.1	-2.91
PGM-20	5.87	1819	222	69	0.084	1.00	0.00	3084	44	30	1.44	47.64	414	1.46	12.00	-29.4	-2.61
PGM-21	6.54	1819	213	62	0.337	0.35	0.08	3012	35	31	1.21	47.98	415	1.22	3.95	-33.2	-3.27
PGM-31	5.74	1764	213	63	0.132	0.27	0.08	2926	30	26	1.27	45.21	419	1.73	7.92	-28.4	-3.09
PGM-45	6.03	1754	224	53	0.033	0.54	0.00	2953	37	26	1.44	46.02	443	1.04	7.66	-28.9	-3.05

plot 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 concentrations at the periphery of the Miravalles geothermal field.

Samples near to the sulphate corner are 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 high concentrations 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 and N-19) have lower chloride concentrations, and are probably of meteoric water origin, heated by steam. The rest of the samples (N-18 and N-16) have neutral pH and very low conductivity and total dissolved solids and represent 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 an elevation of 170 m a.s.l. It is characterized by high total dissolved solids, chloride concentration and conductivity, with a temperature of 54°C and the presence of travertine around it. It is considered to be the outflow of the reservoir which, due to topographic restrictions, has travelled over a long distance.

In Figure 4 a mixing line between fluids of the wells with local groundwater is indicated. The water discharged at Salitral Bagaces (N-13) shows a 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.

The chemical results above are very

similar to those obtained by Giggenbach and Corrales (1992).

4.3 Isotopic composition

Isotopic variations occur in natural systems (gas-water-rock assemblages) as a result of the natural processes taking place 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 high altitude and latitude the rainfalls are isotopically lighter than in the lowlands. Deuterium is used as a natural tracer to locate the recharge areas of a groundwater system and to study the flow patterns. The isotopic analyses of water samples from springs and wells give information about the origin of the field discharges, their age and possible underground mixing processes between different waters, about water rock interaction and steam separation processes (Nuti, 1991).

In Figure 5 the 1997 and 1998 data for the Miravalles fluids are shown in a standard δD vs. $\delta^{18}O$ plot. The data is also given in Tables 1 and 2. Waters from rivers and cold springs define the local meteoric line showing a linear correlation with a slope of 8.42 and a deuterium excess of 12.98, which is close to the world meteoric water line defined by Craig (1961). The variation in the isotopic content of the precipitation in the Miravalles area appears to be a function of the geographic distribution rather than the normal altitude effect (Panichi, 1997). This is explained by the geographical position of Costa Rica, as the Guanacaste Cordillera is affected by precipitation originating both from the Atlantic and Pacific oceans. Also shown in Figure 5 is the isotopic composition of the deep parent water (DPW) as defined by Giggenbach and Corrales (1992).

Tables 1 and 2 in Appendix show the chemical and isotopic composition of springs and wells, respectively, in the Miravalles geothermal field in 1997-1998. The chemical and isotopic composition of the hot and cold springs does not seem 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 and 1998.

In Figure 5 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 that of the parent water (-25‰). 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 discharge of the wells

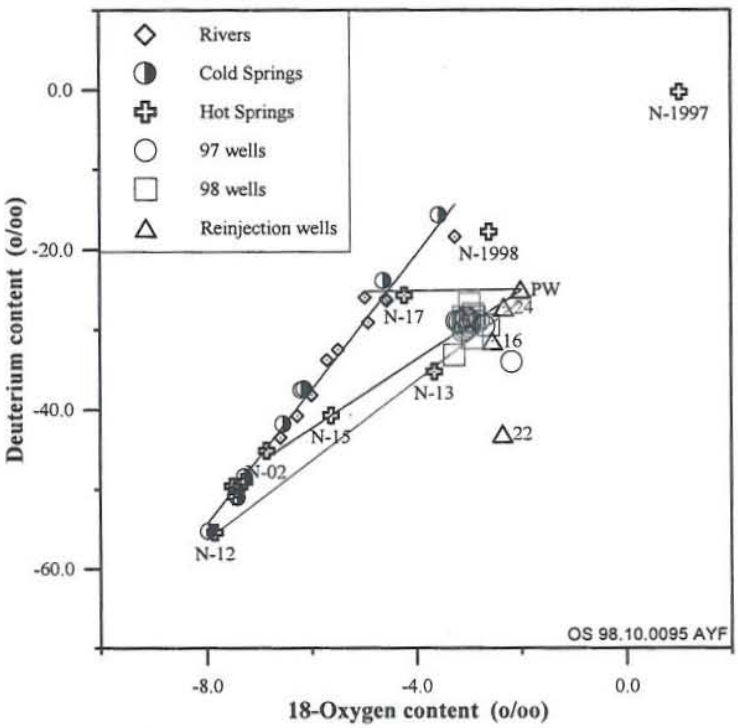

FIGURE 5: Isotopic composition of waters from the Miravalles geothermal field 1997-1998

sits 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 is also suggested in Figure 4.

Figure 6 represents the relationship of the δD and $\delta^{18}O$ against the chloride concentration for samples from cold and hot springs, and wells collected for this project. The production boreholes are close to each other, in the range from -2.18 to -3.27 for $\delta^{18}O$ 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 $\delta^{18}O$ 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 5. The mixing lines shown in Figure 5 are also shown in Figure 6.

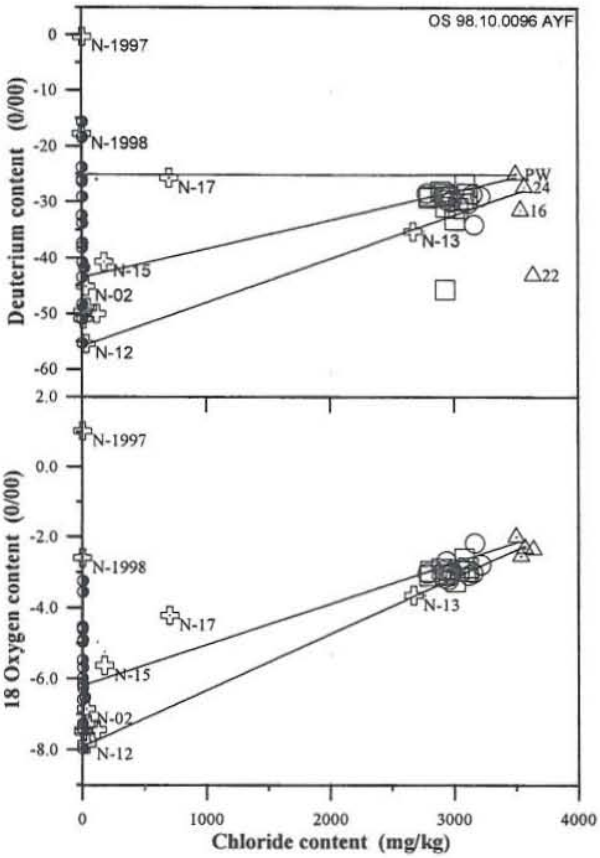

FIGURE 6: δD and $\delta^{18}O$ vs. chloride concentration

5. RESERVOIR EVALUATION

5.1 Chemical and thermodynamic changes with time

In order to evaluate the response of the reservoir to the production load, several parameters (i.e. the enthalpy, temperature logs, chloride concentration in the total discharge, magnesium content in the deep fluid, the Na-K geothermometer (Fournier 1979), quartz geothermometer (Fournier and Potter 1982) and Cl/B ratio) are plotted versus time in Figures 7, 8 and 9 using the borehole data collected from the start of exploitation in 1994 up to the present (Tables 3-14 in Appendix).

All the above mentioned variables are plotted for each production well in use during the last four years and are described below.

Well PGM-11 is located in the northern part of the field and was drilled in 1984-1985 to a depth of 1454 m. Two major feed zones have been identified in this well, the first between 850 and 1050 m depth and the second at 1440 m depth. The chloride content, the temperature logs, the Na-K (Fournier, 1979) and quartz (Fournier and Potter, 1982) geothermometers, the Cl/B ratio and the magnesium content remain constant with time as shown in Figure 7. Only the enthalpy shows a slight tendency to decrease but this can be explained by the uncertainty in the measurements. PGM-11 is separated from the other production wells by the inferred fault called "Las Hornillas".

Well PGM-01 is located in the centre of the field. It is 1300 m deep and only one major feed zone at 850-900 m depth has been observed. Figure 7 demonstrates that enthalpy increases slightly from June 1994

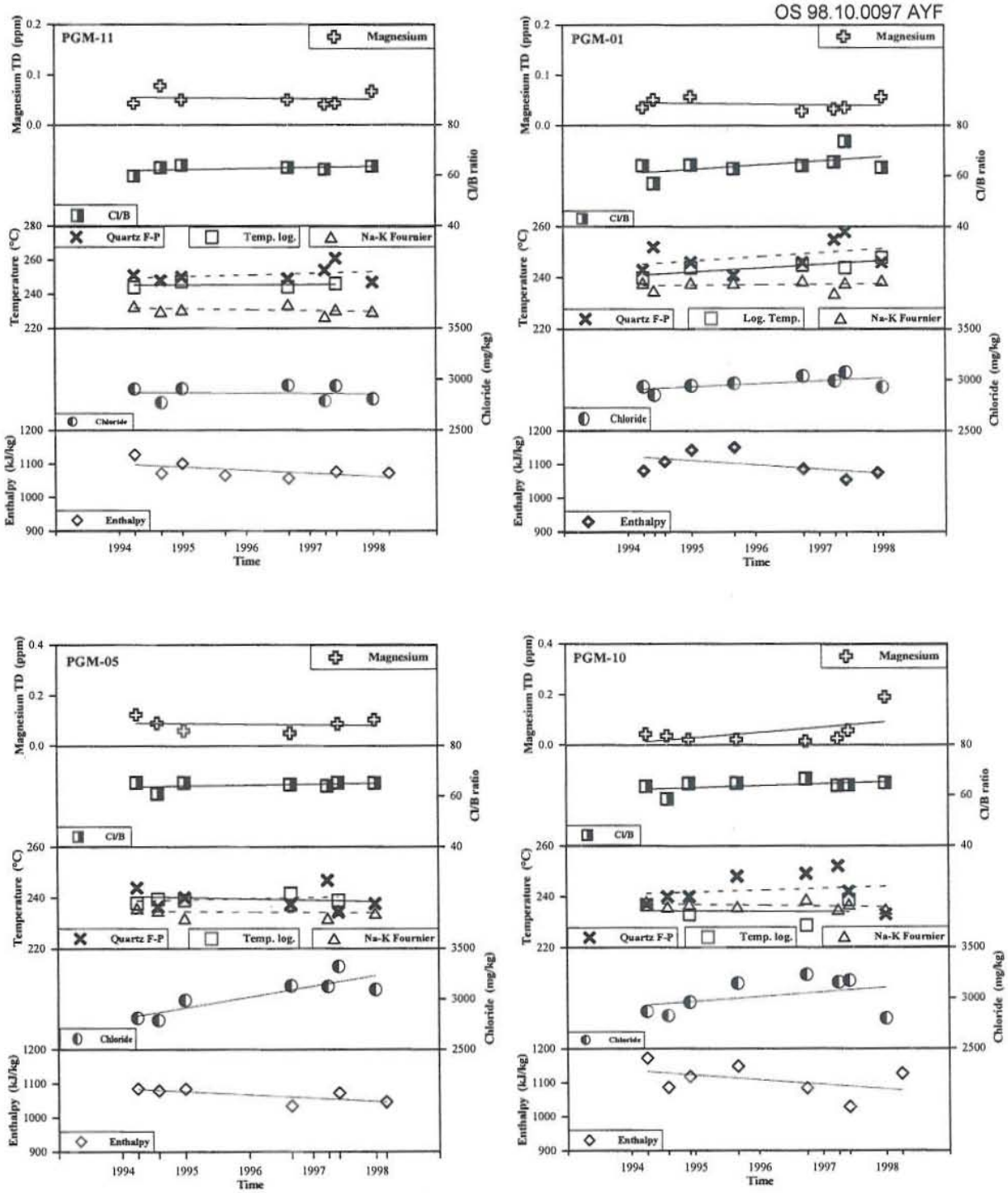

FIGURE 7: Changes with time in wells PGM-01, PGM-05, PGM-10 and PGM-11 in Miravalles

to November 1995, but thereafter it decreases. This behaviour is not followed by other parameters like chloride content, Cl/B ratio, logged temperature and the geothermometer temperature which increase slowly with time. The magnesium concentration remains almost constant, with only small fluctuations.

Well PGM-05 is located in the centre of the field. It is 1854 m deep with one main feed zone at a depth of about 1500-1650 m. This well shows the greatest increase in chloride concentration whereas the other parameters remain almost constant, apart from enthalpy which tends to decrease slightly (Figure 7).

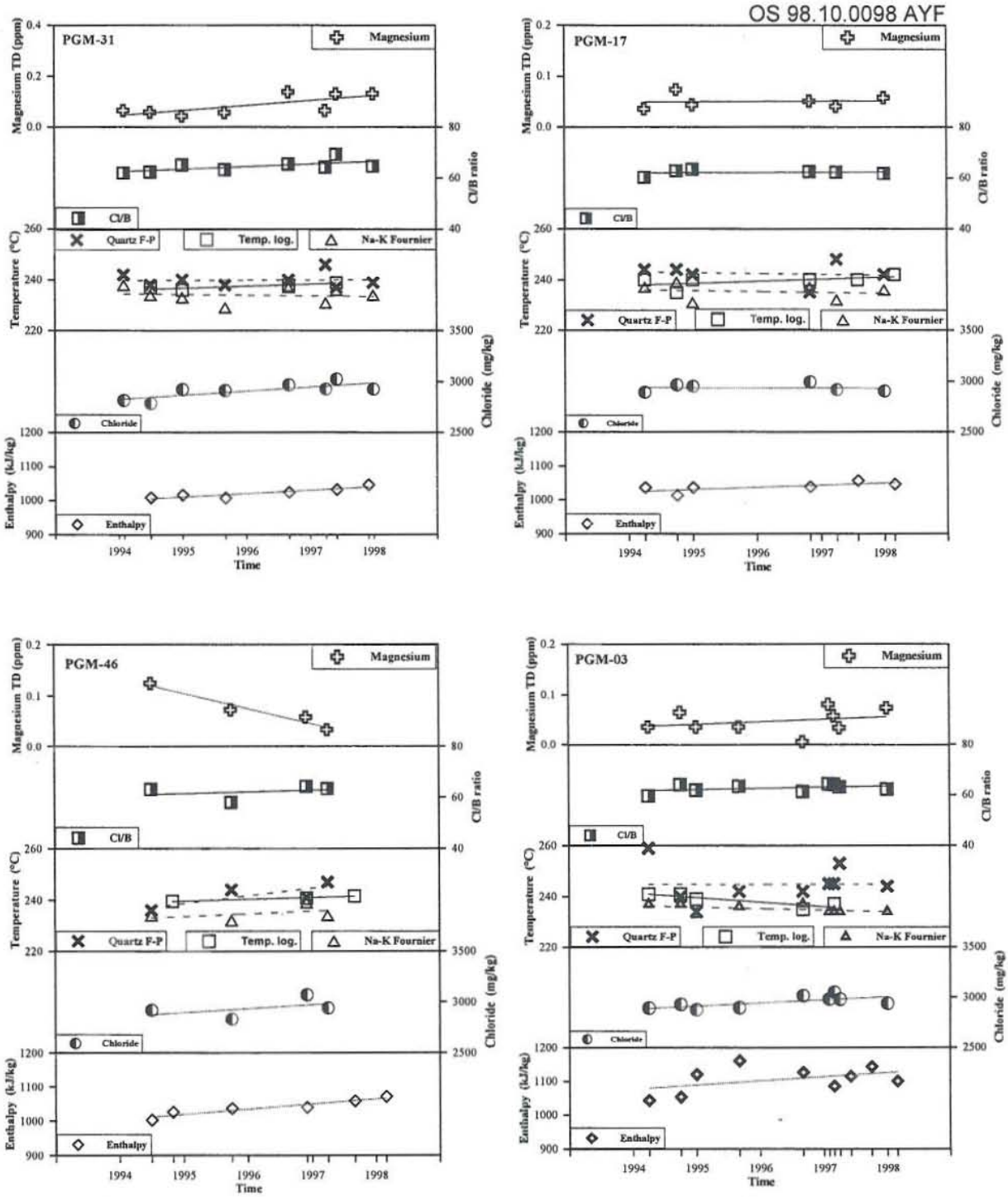

FIGURE 8: Changes with time in wells PGM-03, PGM-17, PGM-31 and PGM-46 in Miravalles

Well PGM-10 is located close to well PGM-01. It is 1804 m deep and has two major feed zones, at 750 and 1250-1450 m depth, respectively. It has the lowest permeability of all the production wells and shows the greatest fluctuations in enthalpy of all the wells within the field. A slight decrease can be observed in the enthalpy values with time (Figure 7). The chloride content shows a tendency to increase from the beginning to November 1995, but thereafter to August 1997 the concentration of chloride remains constant apart from the latest value. The measured temperature decreases until December 1996 when it starts to rise, whereas the Na-K geothermometer shows constant values and the quartz geothermometer an increase with time until June 1997 when it starts to decrease. The Cl/B ratio is

constant and so is the magnesium concentrations until 1997, the last two points show higher concentrations. These could be affected by an analytical error.

Well PGM-31 is also located in the centre of the field, close to wells PGM-01 and PGM-10. It is 1725 m deep and two major feed zones have been identified, at 850-1000 and 1400-1600 m, respectively. All the parameters plotted in Figure 8 show a slight increase with time.

Well PGM-17 is located in the central area. It is 1300 m deep with three major feed zones, around 770-840, at 950-1000 and around 1200-1250 m depth. It is one of the most stable boreholes; the parameters, chemical species and ratios remain almost constant (Figure 8).

Well PGM-46 is located in the centre of the field. It is 1198 m deep and has three major feed zones, at 700, 750-1196 and >1196 m. In this well the enthalpy, the measured temperature and the quartz temperature have a tendency to rise, whereas the chloride content, the Cl/B ratio and the Na-K temperature show constant values with time. The magnesium content shows a steep decrease (Figure 8).

Well PGM-03 is located in the centre of the field close to PGM-17, PGM-46 and PGM-19, the second acid fluid well in Miravalles. It is 1162 m deep with one major feed zone around 700-800 m. The behaviour of this well is irregular; the enthalpy increases very fast from March 1994 to November 1995, but thereafter it is almost constant (Figure 8). On the other hand, the chloride concentration, the Na-K temperature and the Cl/B ratio remain constant with time. Acid has been injected into this well three times to remove calcite deposits. Because of broken casing, the flashing zone cannot be reached by the inhibition system and the well gets blocked very fast (3 months). This may explain the anomalous values for silica and magnesium concentrations.

Well PGM-45 is used to feed one of the 5 MW back pressure units. It is located in the centre of the field, 959 m deep, with three feed zones (at 620, 700-750 m and 930 m) and the data from this well is meagre. The parameters, species concentrations and ratios show almost constant values with time (Figure 9).

Well PGM-20 is located in the southern part of the production area. It is 1700 m deep and has three major feed zones (at 830, 1320 and 1620 m). The chloride content shows a strong tendency to increase with time, and so does the logged temperature and the Na-K temperature. Enthalpy, Mg-concentration and Cl/B ratio show almost constant values. Only the quartz temperature curve has a different shape, but during the last year it tended to be similar to the others (Figure 9).

Well PGM-12 is located in the southern part of the production area. It is 1597 m deep and has two major feed zones (at 650-750 and 1000 m). Together with PGM-05 this well shows the greater increase in chloride concentration, but the last samples show a slight decrease (Figure 9). The enthalpy values increased with time, until November 1997 after which they tended to decrease. The Cl/B ratio and the measured temperature have a tendency to increase with time whereas geothermometers temperatures showed constant values. A different pattern is shown by the magnesium content which decreases with time, similar to that of PGM-46 water.

Well PGM-21 is located in the southeastern part of the production area. It is 1715 m deep and has two major feed zones (at 1000-1100 and 1450-1550 m). The enthalpy, logged temperature and magnesium content show a tendency to increase with time, while the other parameters show almost constant values (Figure 9).

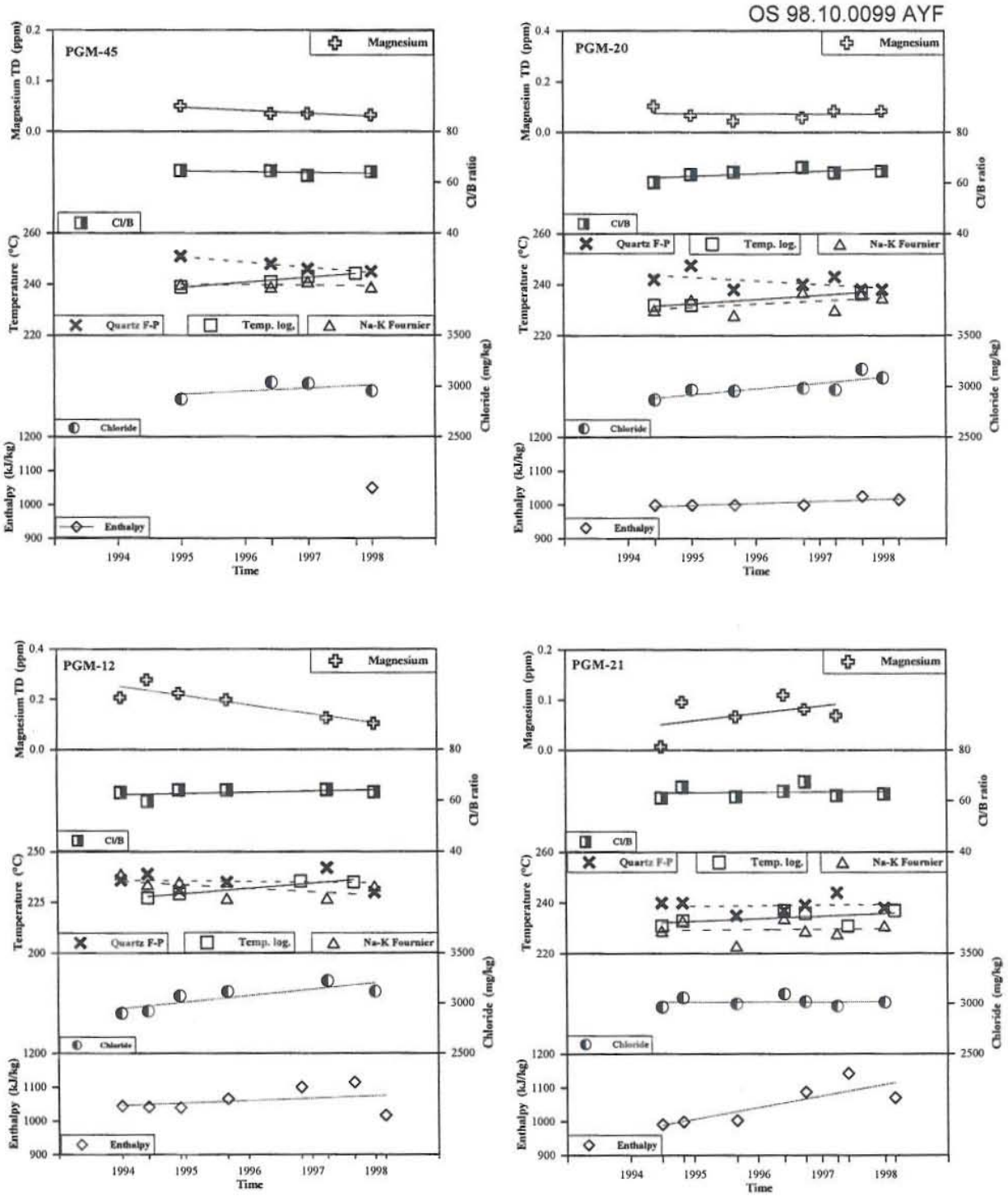

FIGURE 9: Changes with time in wells PGM-12, PGM-20, PGM-21 and PGM-45 in Miravalles

6. 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.

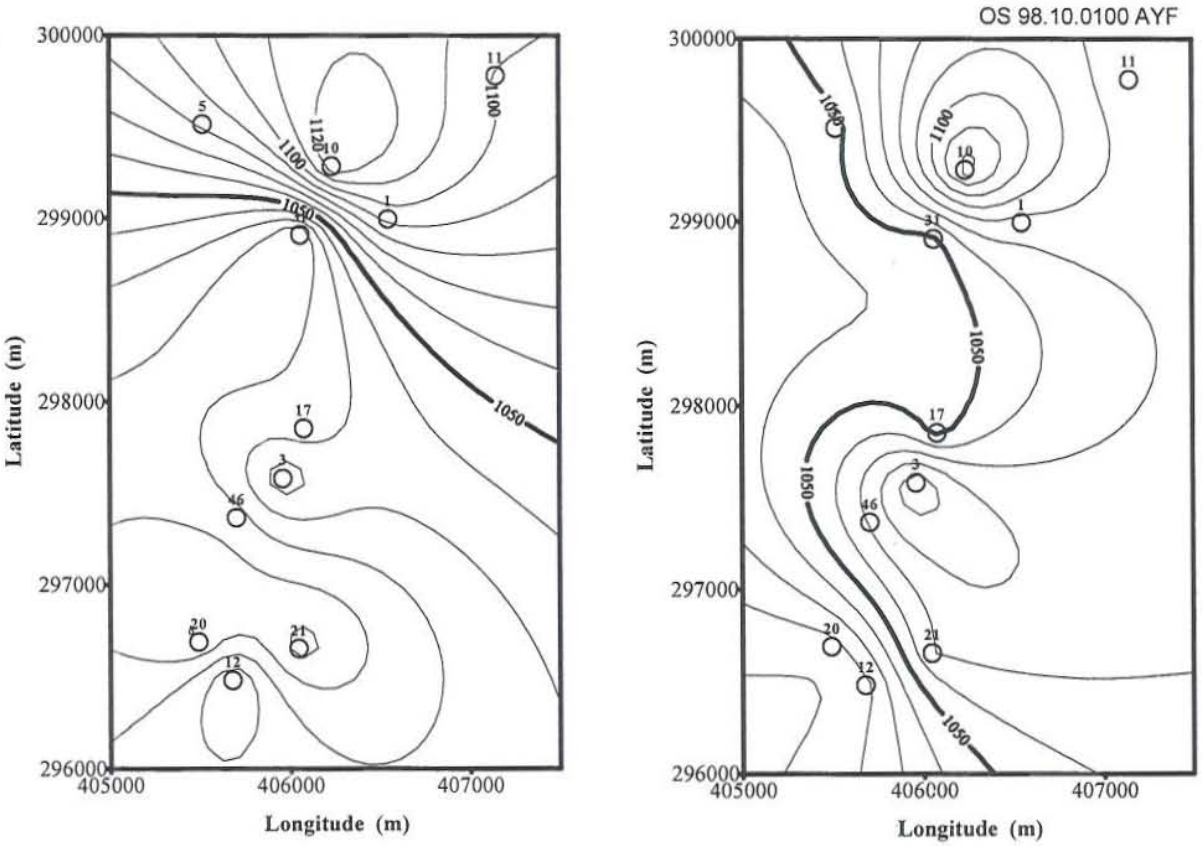

FIGURE 10: Enthalpy contours in 1994 (left) and 1998 (right) for Miravalles geothermal field

6.1 Changes in distribution between 1994 and 1998

In Figure 10 comparison is made between the enthalpy distributions measured in 1994 and in 1998. It shows that the enthalpy distribution during the early exploitation months (1994) is smooth and relatively little scattering is observed in the enthalpy values (1000-1130 kJ/kg). Higher values of around 1100 kJ/kg were observed in the northern wells (PGM-11, PGM-10, PGM-01, and PGM-05). Lower enthalpies of 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 for easier recognition of the changes within the production zone. The 1998 enthalpy values are very similar to the 1994 values, though some trends can be observed. One of these is a clear tendency towards increased enthalpy shown by wells in the central part of the production field towards the southeast (PGM-03, PGM-46, PGM-21,and for some extent PGM-17). This is probably effect of two-phase development (boiling). Two trends towards decreasing enthalpy 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 waste water into wells PGM-22 and PGM-24.

A comparison is made between the reservoir chloride contours from 1994 and 1998 in Figure 11. The reservoir chloride distribution during the first year of exploitation shows a smooth distribution like that of the enthalpy contours with values ranging between 2800 and 3000 ppm, with the maximum values in the eastern part of the production field and the lowest chlorine contents in the northern and western parts of the field. The 3000 ppm contour line is enhanced on both maps in order to recognize clearly the changes within the production zone. The 1998 reservoir chloride concentration differs considerably from the 1994 values (about 200 ppm) in fluids from some wells, whereas others show almost the same 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. Waters from wells PGM-03, PGM-46, PGM-21,and PGM-17 also show a slight tendency towards increased chloride concentrations.

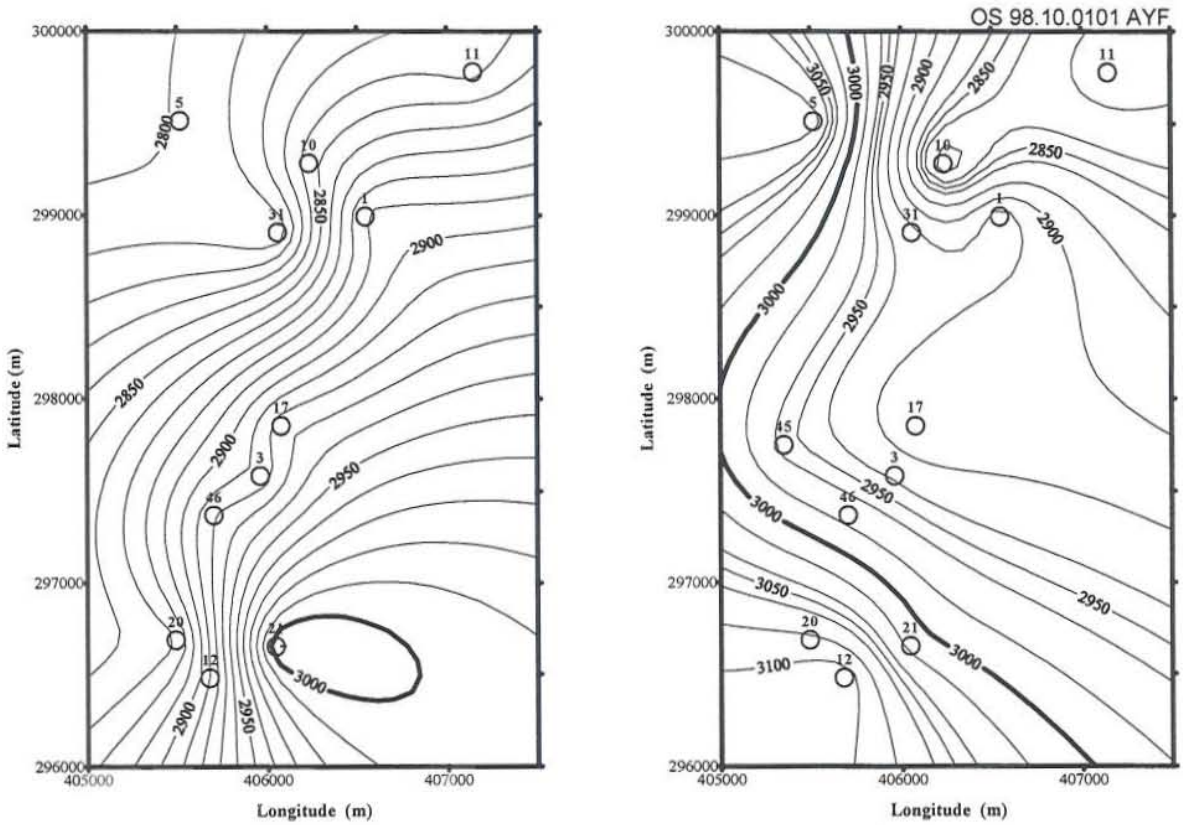

FIGURE 11: Reservoir chloride distribution in 1994 (left) and 1998 (right)

In Figure 12 a comparison is made between the Cl/B ratio contours from 1994 and 1998. The distribution in 1994 indicates small variations within the field as the values lie between 60 and 64, with the high values > 63 found in the northern boreholes and in well PGM-21. The 63 contour line is enhanced on both maps. After four years of exploitation, the southern wells have become similar to the north-central wells, and only the wells in the east (PGM- 03, PGM-17 and PGM-21) have values below 63. Boron remains in its volatile form to be carried in the vapour phase even at quite low temperatures. It is therefore likely that the separated water is lower in boron than the reservoir fluid. The reinjection programme can therefore explain the rise of Cl/B ratio in the north, close to PGM-05 and PGM-10 and in the south close to boreholes PGM-12 and PGM-20.

The reservoir magnesium contours in 1994 show high values in the south (between wells PGM-12 and PGM-21) and lower values in the north (Figure 13). The 0.07 ppm contour line is enhanced on both maps. After four years of exploitation, lower values, < 0.07 ppm, are found within two areas, one in the north which includes wells PGM-01and PGM-11 and the other in the east (wells PGM-03, PGM-17 and PGM-45). Well PGM-31 is located between these zones. Its fluid shows an increased Mg content from 0.063 to 0.132 ppm between the years 1994 and 1998. This can be explained by the inflow of groundwater with a high magnesium content. However, other parameters for this well, shown in Figure 8, do not reflect this process. The 1998 contours show a tendency towards decrease in magnesium content to the south near wells PGM-20 and PGM-12. This is likely caused by the reinjection water.

6.2 Isotopic change with time

The stable isotopes in the waters are a useful tool for monitoring possible changes in the reservoir because the geothermal waters, the reinjection water and the local groundwater have a different isotopic composition.

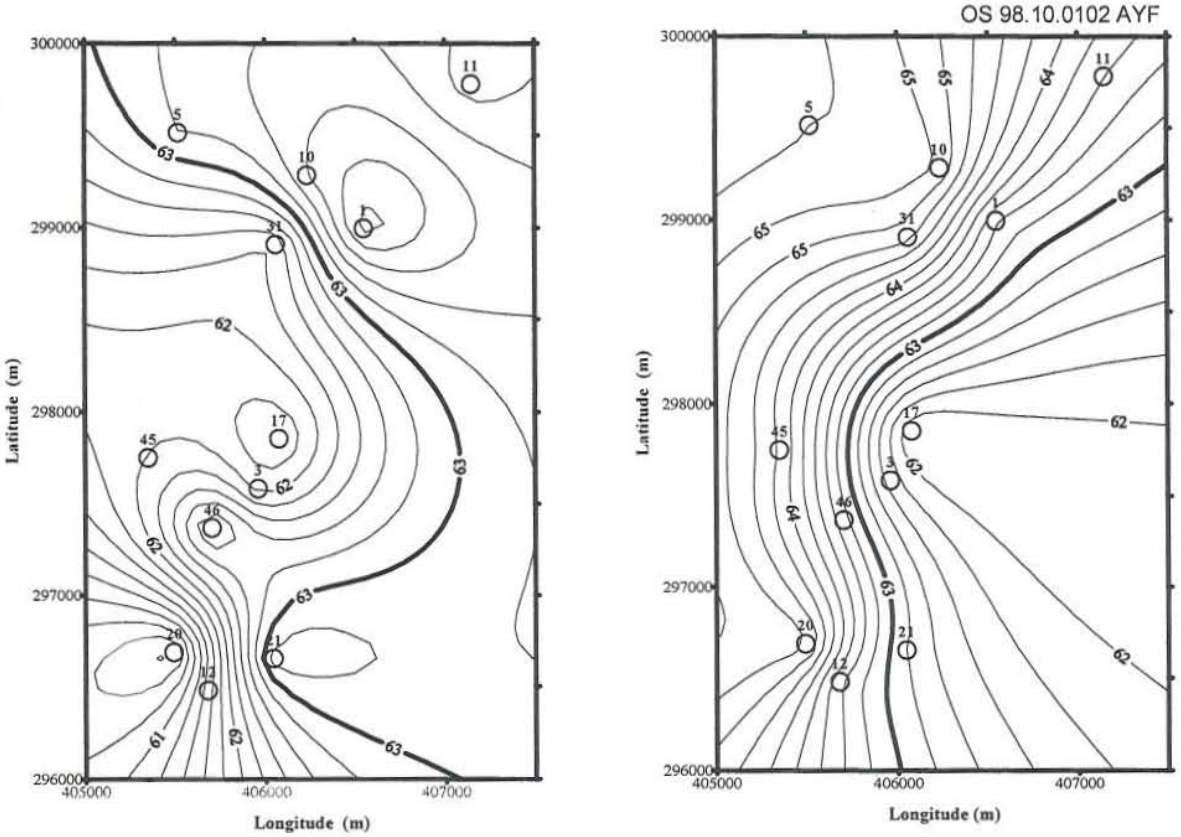

FIGURE 12: Cl/B distribution in 1994 (left) and 1998 (right) for the Miravalles geothermal field

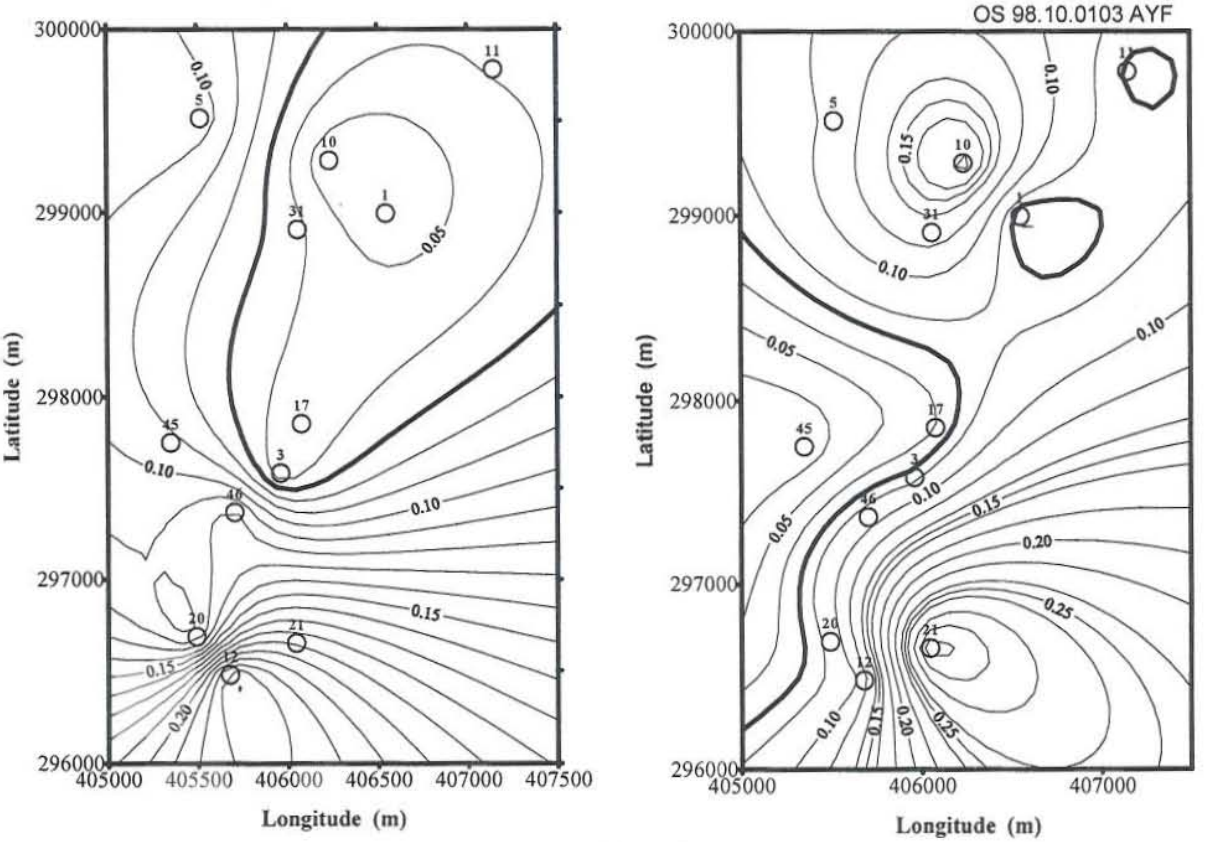

FIGURE 13: Reservoir magnesium contours in 1994 (left) and 1998 (right) for the Miravalles field

In order to examine closely the scale of data from the geothermal wells, the δD vs $\delta^{18}O$ plot is expanded in Figure 14. Although the wells are close to each other there are apparently two trends, isotopic enrichment and depletion, respectively. The apparent enrichment trend is shown from production wells toward reinjection well PGM-24, but the apparent isotopic depletion is shown only for well PGM-21, likely caused by mixing with isotopically lighter water. This should be confirmed by careful chemical and isotopic monitoring.

The 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 regard to the other isotopic data from the area (see Figures 5 and 6).

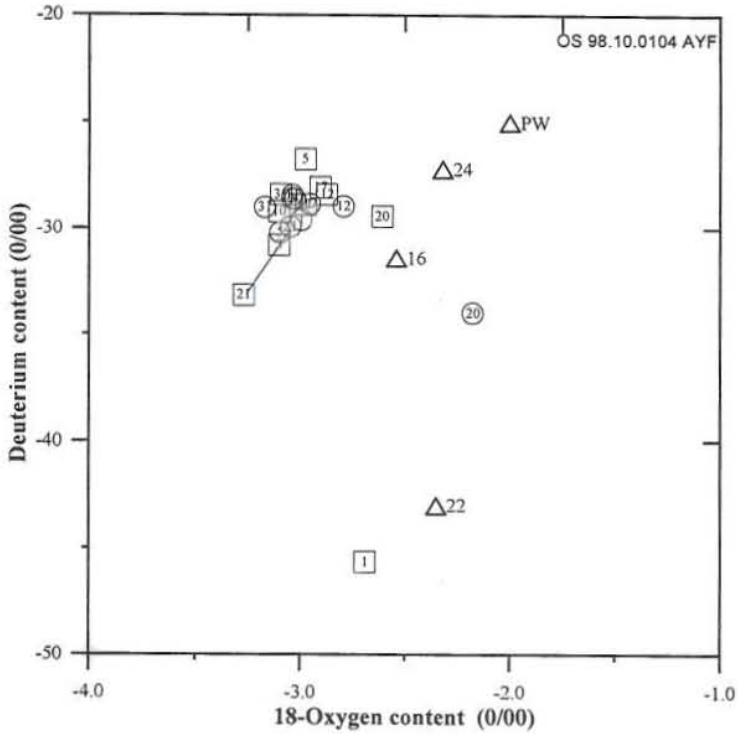

FIGURE 14: δD vs $\delta^{18}O$ for the Miravalles geothermal wells

7. MINERAL EQUILIBRIUM

The state of saturation for calcite, talc and chrysotile in the aquifers for each well has been evaluated using the WATCH program (Arnórsson et al., 1982; Bjarnason,1994). The results are presented in Figure 15.

All deep fluids of the Miravalles wells, with the exception of the PGM-12 fluid, appear to be supersaturated with respect to chrysotile below 230-240°C, whereas at higher temperatures all the fluids are undersaturated. The equilibrium temperature for chrysotile in the Miravalles deep water is, therefore, at 230-240°C.

All deep fluids of the Miravalles wells with the exception of the PGM-12 fluid appear to be supersaturated with respect to talc below 235-245°C. Above this range of temperatures the fluid is undersaturated or close to saturation. The equilibrium temperature for this mineral in the Miravalles deep water is, thus, at 235-245°C.

All deep fluids of the Miravalles wells with the exception of the PGM-12 fluid appear to be supersaturated with respect to calcite. The over-saturation occurred through the whole temperature range chosen for this study (200-280°C).

The undersaturated state of the PGM-12 fluid may have three explanations. Firstly, it can be affected by the waste water injection started in 1994 as the reinjection water is characterized by a lower magnesium, calcium carbonate and non-condensible gas (NCG) content. Secondly, precipitation of calcite and chrysotile or talc will decrease the content of calcium and magnesium in the fluid sampled.

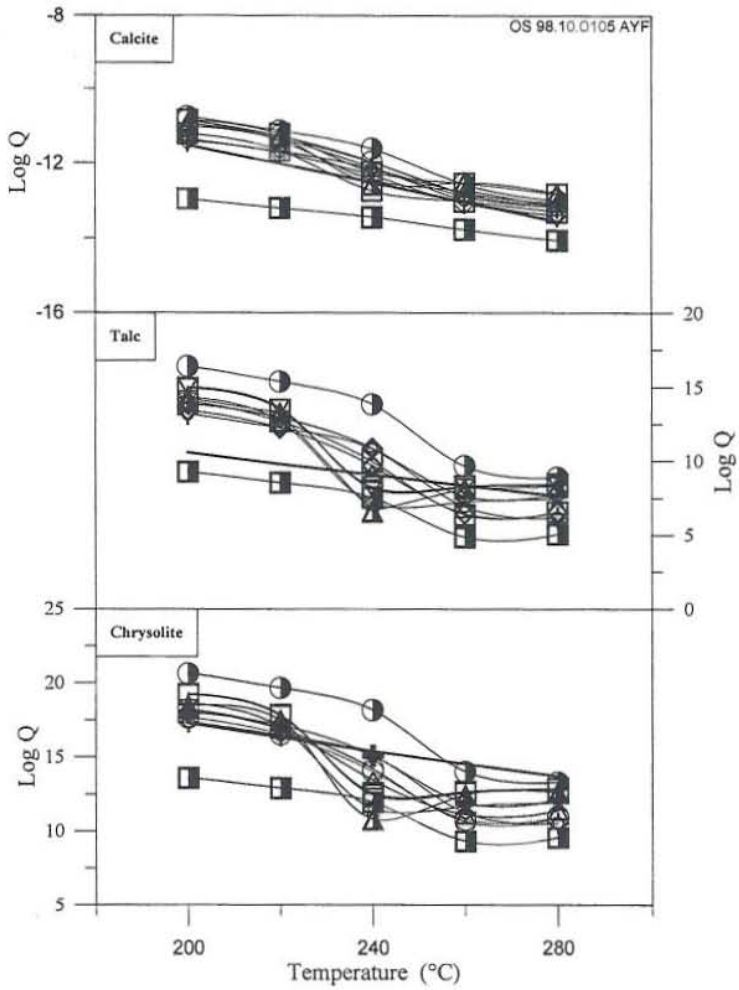

FIGURE 15: State of chrysotile, talc and calcite saturation for Miravalles fluids, the solid line is the saturation line (for symbols, see Figure 16)

The non-condensible gas concentration would still be relatively high because the supply of CO_2 should be sufficient to saturate the water with calcite (Arnórsson, 1989). Thirdly, the undersaturation could be caused by extensive boiling starting in the aquifer causing precipitation within the aquifer.

Each well has been evaluated by using the WATCH program in order to study the variations of calcite-saturation with time (Figure 16). Figure 16 shows that in the early years the north and northwestern wells (PGM-01, PGM-05, PGM-10 and PGM-11) together with well PGM-12 had a higher degree of supersaturation than the central and southern wells. The supersaturation is almost constant with time from 1994 until 1997, but thereafter it tends to decrease. The same occurred with doses of an inhibitor used for each well, which are reduced from 4,5 ppm to 2,0 ppm (Sánchez, personal communication). Usually, this behaviour indicates extensive boiling in the aquifer and, thus, calcite precipitation inside the well decreases but will instead occur in the formation. The pore volume in the reservoir is much larger than in the wells and can thus cope with calcite deposition without observable deterioration of permeability for periods as long as the lifetime (20-50 years) of individual wells (Arnórsson, 1989).

The greatest variation is shown by the fluids at well PGM-12 which is undersaturated, and PGM-21 which is supersaturated with respect to calcite, at present. The fluids discharging from PGM-21 are likely to be affected by mixing another geothermal fluid with a higher magnesium content, a higher Na-K ratio and a higher non-condensible gas content, similar to the fluid discharged by well PGM-29.

The state of saturation for calcite, chrysotile and talc when the water boils adiabatically is presented in Figure 17 as a function of the temperature of the boiled water. The chrysotile and talc supersaturation increases after boiling and in all cases this supersaturation is greater for talc than for chrysolite. Magnesium silicate scaling could become a problem with time even though the quantity of scaling in the Miravalles wells at present is relatively small.

The potential of calcite scaling in the Miravalles fluids is still high as is indicated in Figure 17 and the maximum degree of supersaturation occurs at 220-230°C.

8. DISCUSSION

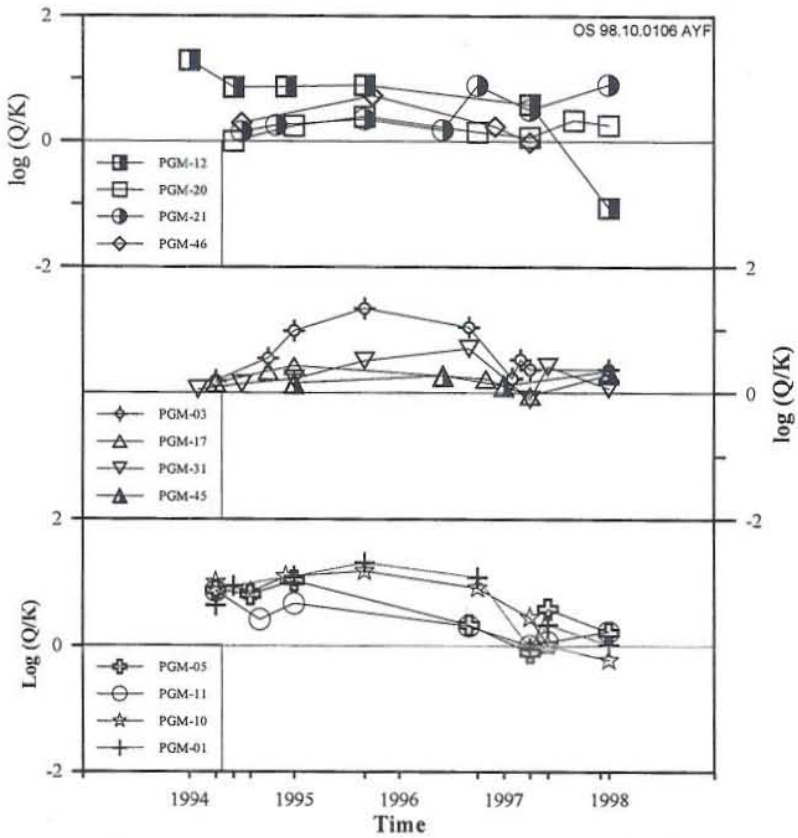

FIGURE 16: State of saturation of the calcite with time for Miravalles fluids

Exploitation of a geothermal field produces a pressure drop in the reservoir (drawdown) as a natural consequence of fluid and energy extraction. The drawdown or pressure drop 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 chemical composition of the fluids (chemical front) are observed before the thermal front in the well. Hence, chemical monitoring of the fluids may give a warning in time for preventive measures. Measurements of flowrate, 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, chemical monitoring should be expanded to replace direct measurements. However, both monitoring programmes are necessary in order to get a good understanding of the processes taking place in the reservoir and to optimize 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).

According to this study, most of the reservoir parameters have been affected by the exploitation of the Miravalles field. Wells PGM-17 and PGM-11 are the most stable boreholes so far, only the enthalpy shows a slight possible change which may be due to measurement uncertainties. In general, in the early years (1994-96) the enthalpy increased in most of the wells with time. Increasing enthalpy is a normal process in most high-temperature liquid-dominated reservoirs. It is caused by the development of two-phase (boiling) zones in the reservoir, mainly in the shallow parts of the reservoir as a consequence of the pressure drawdown produced by fluid extraction. After 1996, some wells show lower enthalpy (PGM-01, PGM-05 and PGM-10). The latest enthalpy measurements of wells PGM-12 and PGM-21 also showed low values. The enthalpy usually decreases when the reservoir is affected by the inflow of colder fluids. These fluids could be cold groundwater or geothermal water (reinjection water). Groundwater is usually characterised by a high magnesium content, low chloride concentrations and total dissolved solids. On the other hand, the reinjection water usually has high chlorine content and total dissolved solids but 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 increase shown in wells PGM-05 and PGM-12 is, however, due to the arrival of reinjection water in these wells. Contour maps for chemical parameters show the effects caused by reinjection, in the north (PGM-05) and in the south (PGM-12). The magnesium concentration in the reservoir fluid tends to decrease

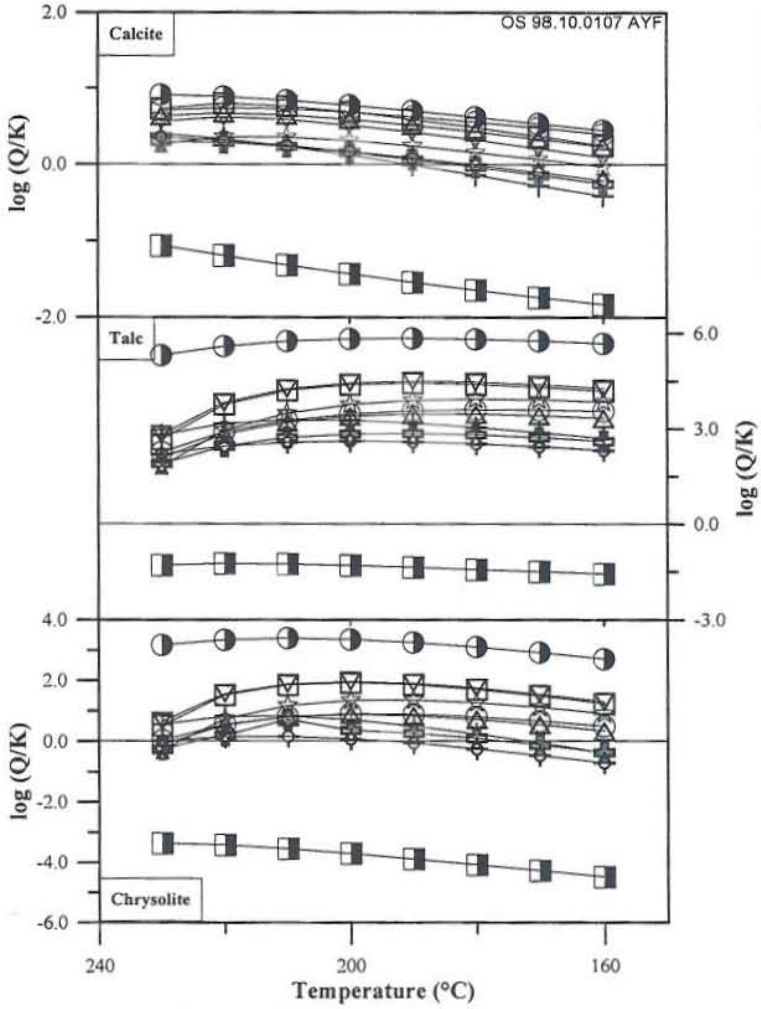

FIGURE 17: Change of saturation index (log (Q/K) of calcite) chrysolite and talc during adiabatic boiling of the geothermal water from Miravalles wells

in most of the boreholes with time. Only fluids from wells PGM-21 and PGM-31 show increasing magnesium concentrations.

The chemical and isotopic composition of the hot and cold springs in the Miravalles field seem, however, not to be affected by exploitation of the reservoir (Appendix, Table 1). The isotopic composition of the fluid discharged by the Miravalles wells in 1997 and 1998 is almost identical. The δD range for the 1997 samples is -28.6 to -30.2 and for the 1998 samples -28.1 to -33.2. The $\delta^{18}O$ range for the 1997 is from -2.69 to-3.1 and for the 1998 samples from -2.61 to -3.10. The 1997 values 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. The PGM-21 fluid shows a slight indication of mixing with groundwater when the 1997 sample is compared to the 1998 sample, but this amounts only to 3‰ in δD and 0.5 ‰ in $\delta^{18}O$. Only two samples show a 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 m a.s.l. and its water is characterized by very low conductivity and low total dissolved solids. 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 collected during the rainy season, but the 1998 sample during the dry season. The latter is probably more affected by evaporation than the 1997 sample due to the seasonal effect (different temperatures). Hornillas is a geothermal manifestation in the north of the field, characterized by the presence of fumaroles, a 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 isotopically heaviest sample of 1998 is from well PGM-24. This well is used for hot reinjection and the isotopic composition of this fluid reflects the effects 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‰). Such waters (2 samples) are found within the northern part of the field, thus defining the recharge area.

It has been proposed that in geothermal systems a chemical equilibrium between all major dissolved constituents, except chloride and alteration minerals, is closely approached (e.g. Giggenbach, 1981; Arnórsson et al., 1983). When the reservoir fluid rises in discharging wells, it boils and the chemical

equilibrium existing in the aquifer is upset. All deep fluids of the Miravalles wells with the exception of the PGM-12 fluid appear to be undersaturated with respect to talc and chrysotile and supersaturated with respect to calcite. Adiabatic boiling will increase the scaling potential of these minerals.

9. RESULTS

9.1 Conclusions

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

1. At present the chemical and isotopic compositions of the hot and cold springs is 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 water is found 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 fluid chloride content. The greatest increase is noted in wells PGM-05 and PGM-12.

6. The reinjection water is detected in the northern part and south of the production zone and probably affects the temperature of wells located in these areas.

7. In the east (PGM-21) another possible inflow is indicated, however from the available data this is not clear.

8. The chemical trends detected in this study will probably become more pronounced as fluid production increases when the second condensing unit starts production.

9. The equilibrium temperature for chrysotile and talc in the Miravalles deep water is at 230-240°C and 235-245°C, respectively.

10. All deep fluids of Miravalles wells, with the exception of PGM-12 fluid are supersaturated with respect to calcite. Increased boiling will reduce calcite precipitation within the wells.

11. Magnesium silicate scaling could become a problem with time, but mainly in the reinjection pipelines.

9.2 Recommendations

When the second unit starts:

1. Measurements of flowrate, pressure and temperature for each well should be made at least once a year, especially in wells located in areas affected by reinjection fluids, in order to detect or confirm changes in the reservoir performance.

2. At least three monitoring wells are recommended in the production area and one in the

reinjection zone. Monitoring wells should be located in the production zone in order to detect changes in the pressure due to exploitation. A monitoring well in the reinjection zone should be located with the intent to monitor the effect of waste water injection.

3. Chemical monitoring programme should be expanded from once to three times a year and one of these should coincide with the measurement of physical parameters.

4. Stable isotope monitoring should be incorporated into the programme 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 estimate the amount of reinjected water showing up in the production wells. When a tracer is injected into well PGM-22, wells PGM-05, PGM-10, PGM-08 and PGM-42 should be monitored, and when a tracer is injected into well PGM-24, wells PGM-12, PGM-20, PGM-46, PGM-49 should be monitored.

6. Tracer tests 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 should be injected in wells 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 will continue to be used for injection. The objective of this test is to study the connection between well PGM-04 and productions 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 a chemical and isotopic study of that area.

9. Measurements of the injectivity index for each reinjection well should be made at least once a year.

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APPENDIX 1: Chemical and isotopic composition of springs and wells in the Miravalles field

TABLE 1: Chemical and isotopic composition of springs 1997-1998 in ppm, Miravalles geothermal fields, Costa Rica

Sample No.	Date	Temp (°C)	pH	Cond. (µS/m)	Na^+	K^+	Ca^{+2}	Mg^{+2}	Cl^-	SO_4^{-2}	HCO_3^-	F^-	B	SiO_2	Ionic balance	D ‰	^{18}O ‰
N-0197	10.6.1997	38.00	6.82	542	52	15	60	12.5	41	50	215	0.08	0.64	147	7.97	-50.60	-7.42
N-0198	13/3/98	38.00	6.67	627	52	16	72	15.0	47	64	212	0.20		144	10.32	-47.30	-7.16
N-0297	10.6.1997	57.00	6.55	707	54	19	63	19.8	30	101	281	0.09	0.45	196	0.55	-45.50	-7.00
N-0298	13/3/98	53.00	6.48	754	54	18	102	21.6	34	103	293	0.24		179	10.12	-44.60	-6.72
N-0397	11.6.1997	37.00	5.87	349	20	8	34	11.5	9	27	183	0.08	0.16	124	-0.85	-49.90	-7.44
N-0398	16/3/98	37.00	5.67	394	23	8	57	14.4	8	43	195	0.21		123	10.08	-51.80	-7.46
N-0497	11.6.1997	25	6.69	121	8	2	14	3.0	7	8	56	0.09		80	2.26	-53.60	-7.90
N-0498	16/3/98	23	6.58	113	8	2	14	3.0	4	7	68	0.26		76	-0.33	-56.90	-8.04
N-0597	11.6.1997	24	7.27	128	9	3	15	2.5	6	24	32	0.10		75	8.53	-51.00	-7.39
N-0598	14/3/98	23	7.12	186	8	3	24	3.6	4	53	40	0.23		71	0.99	-51.00	-7.44
N-0697	11.6.1997	21.00	7.11	74	7	2	6	1.5	6	11	17	0.22	0.12	52	5.24	-37.00	-6.30
N-0698	15/3/98	17.00	6.50	81	6	2	5	1.6	4	12	29	0.53		48	-12.17	-37.90	-6.19
N-0897	12.6.1997	20.00	7.66	65	11	2	9	2.3	4	5	26	0.03		30	27.01	-23.90	-4.62
N-0898	15/3/98	16.00	6.90	22	2	0	4	0.5	6	2	13	0.15		5	-9.11	-15.70	-3.56
N-0997	12.6.1997	26.00	6.22	241	14	4	38	7.0	5	23	109	0.11	0.12	90	14.41	-48.50	-7.29
N-0998	16/3/98	23.00	6.14	242	10	3	37	7.9	5	24	120	0.27		86	7.81	-48.30	-7.26
N-1097	13.6.1997	48	6.24	1030	130	23	97	27.2	126	21	419	0.11	1.74	166	10.41	-50.40	-7.39
N-1098	14/3/98	46	6.10	1070	120	22	99	29.7	114	21	427	0.24		161	10.71	-49.60	-7.48
N-1197	13.6.1997	43.00	6.41	766	59	17	92	35.5	10	63	432	0.17	0.37	152	9.87	-49.60	-7.51
N-1198	13/3/98	43.00	6.27	774	54	17	115	38.2	10	61	430	0.38		149	15.39	-39.70	-7.63
N-1297	13.6.1997	43.00	5.70	376	66	12	12	1.5	33	6	157	0.08	1.10	134	3.39	-56.10	-7.79
N-1298	13/3/98	43.00	5.44	398	64	12	14	1.8	36	5	173	0.25		128	-0.13	-54.60	-7.90
N-1397	13.6.1997	60.00	6.91	9570	2090	74	60	4.2	2630	112	1240		45.00	130	-0.33	-35.20	-3.65
N-1398	13/3/98	47.00	6.42	10100	2178	86	129	6.8	2717	126	1260	0.82		105	2.01	-38.90	-3.56
N-1597	18.6.1997	37.00	2.61	3550	70	11	471	90.0	212	1755		0.06	0.80	133	-10.65	-40.70	-5.63
N-1598	16/3/98	35.00	3.04	3140	70	10	543	115.7	143	1726		0.21		107	0.14	-32.60	-5.70
N-1697	18.6.1997	22.00	6.19	830	41	7	154	32.2	29	286	116	0.19	0.22	103	17.35	-33.90	-6.67
N-1698	16/3/98	27.00	5.74	942	27	6	174	40.4	15	361	124	0.54		99	14.67	-41.50	-6.54
N-1797	18.6.1997	63.00	2.01	6950	55	2	88	29.7	675	2757		0.09	1.57	275	-78.27	-24.50	-4.29
N-1798	14/3/98	61.00	1.93	7270	57	2	140	7.1	730	2914		0.26		258	-77.82	-26.90	-4.15
N-1897	18.6.1997	24.00	6.64	328	14	4	51	5.8	8	122	27	0.15	1.57	275	7.48	-35.80	-6.10
N-1898	14/3/98	24.00	6.37	357	10	3	44	5.4	4	110	28	0.46		68	4.92	-39.00	-6.17
N-1997	18.6.1997	73.00	1.78	8110	18	7	32	9.0	5	1882	0	0.02	0.40	367	-84.47	-0.30	1.02
N-1998	16/3/98	86.00	1.98	6490	18	4	40	4.6	2	1538	0	0.13		288	-81.61	-17.80	-2.60

TABLE 2: Isotopic composition of wells 1997-1998, Miravalles geothermal field, Costa Rica

Well	Enthapy	$P_{sep.w}$	x	^{18}O			D		
1997	(kJ/kg)	(bar-a)		W.S.	C.S.	TD	W.S.	C.S.	TD
PGM-01	1061	7.4	0.17	-2.55	-5.17	-3.00	-29.0	-32.6	-29.6
PGM-03	1140	6.6	0.22	-2.47	-5.06	-3.04	-28.2	-30.0	-28.6
PGM-05	1072	10.5	0.15	-2.72	-5.23	-3.10	-29.4	-34.7	-30.2
PGM-10	1029	7.0	0.16	-2.56	-5.47	-3.03	-27.5	-34.3	-28.6
PGM-11	1075	9.1	0.16	-2.61	-5.29	-3.04	-27.8	-31.7	-28.4
PGM-12	1114	7.4	0.20	-2.24	-5.01	-2.79	-28.0	-32.8	-29.0
PGM-17	1056	7.1	0.17	-2.47	-5.32	-2.95	-27.8	-34.0	-28.9
PGM-20	1024	7.5	0.15	-2.13	-2.44	-2.18	-35.3	-26.6	-34.0
PGM-21	1142	4.9	0.24	-2.44	-4.97	-3.05	-28.8	-33.5	-29.9
PGM-29	1008	8.8	0.13	-2.83	-5.58	-3.22	-27.8	-33.9	-28.9
PGM-31	1076	6.7	0.19	-2.64	-5.43	-3.17	-28.0	-33.4	-29.0
PGM-46	1008	8.8	0.13	-2.36	-4.90	-2.69	-29.3	-31.1	-29.5

Well	Enthapy	$P_{sep.w}$	x	^{18}O			D		
1998	(kJ/kg)	(bar-a)		W.S.	C.S.	TD	W.S.	C.S.	TD
PGM-01	1055	6.5	0.18	-2.33	-4.35	-2.69	-48.3	-33.4	-45.6
PGM-03	1140	6.6	0.22	-2.45	-5.43	-3.10	-29.5	-35.4	-30.8
PGM-05	1072	10.5	0.15	-2.57	-5.29	-2.98	-25.7	-32.7	-26.7
PGM-08	1047	5.2	0.19	-2.30	-5.58	-2.92	-29.7	-36.8	-31.1
PGM-10	1029	7.0	0.17	-2.63	-5.41	-3.10	-27.6	-37.0	-29.2
PGM-11	1075	9.1	0.16	-2.53	-5.26	-2.97	-27.9	-34.0	-28.9
PGM-12	1114	7.4	0.20	-2.35	-5.00	-2.87	-27.0	-34.1	-28.4
PGM-16						-2.54			-31.4
PGM-17	1056	7.1	0.17	-2.41	-5.28	-2.91	-26.6	-35.1	-28.1
PGM-20	1024	7.5	0.15	-2.13	-4.78	-2.61	-28.0	-32.3	-29.4
PGM-21	1142	4.9	0.24	-2.40	-4.52	-3.27	-29.8	-34.2	-33.2
PGM-22						-2.35			-43.0
PGM-24						-2.32			-27.2
PGM-29	1008	8.8	0.13	-2.83	-5.58	-3.22	-27.8	-33.9	-28.9
PGM-31	1076	6.7	0.19	-2.51	-5.64	-3.09	-26.9	-35.0	-28.4
PGM-43	1036	4.3	0.20	-2.39	-5.78	-3.06	-26.7	-38.1	-29.0
PGM-45	1057	9.1	0.15	-2.64	-5.32	-3.05	-28.0	-33.9	-28.9

TABLE 3: Chemical composition of fluids of well PGM-01 with time, Miravalles geothermal field-Costa Rica

Date	Jun 94	Aug 94	Mar 95	Nov 95	Dec 96	Jun 97	Aug 97	Mar 98
P.sep. (bar a.)	0.94	0.94	0.94	0.94	0.94	7.39	0.94	6.44
pH	8.08	8.16	8.11	8.32	8.23	7.61	7.94	7.60
Cond. (µS/cm²)	12400	12100	12600	12300	12600	11200	13425	11550
Na^+ (ppm)	2462	2327	2442	2450	2535	2160	2526	2141
K^+	313	284	308	309	323	262	319	273
Ca^{+2}	54	59	62	64	68	58	73	63
Mg^{+2}	0.05	0.07	0.08	0.03	0.04	0.04	0.05	0.07
Li^+	5.83	6.26	6.26	6.18	5.71	4.85	5.58	5.03
Rb^+	1.01	0.95	0.92	0.98	0.94	0.85	0.94	0.74
Cs^+	0.65	0.71	0.65	0.54	0.57	0.52	0.55	0.48
$Al_{(tot.)}$	0.27	0.43	0.36	0.64	1.26		0.79	0.41
$Fe_{(tot.)}$	0.02	0.06	0.00	0.00	0.08	0.02		0.04
Cl^-	4046	3937	4118	4152	4254	3610	4285	3615
$SO_4^=$	50	29	53	47	52	41	33	34
HCO_3^-	24	35	26	22	13	26	16	19
F^-	1.62	1.23	1.77	1.71	2.38	1.56	2.07	1.89
B	63	69	64	66	66	55	58	57
H_2S	0.00	0.44	1.80	3.01	2.57		1.65	1.47
NH_3	0.63	1.13	0.83	1.12	1.20	1.43	1.22	1.56
$As_{(tot.)}$	11	11	11	10	10	9	10	9
SiO_2	604	659	633	606	631	590	701	553
Ionic balance	1.35	0.08	0.22	0.10	0.68	0.58	0.33	0.52
TDS	8106	8663	8044	8100	8391		8245	6985
CO_2 (mmol/kg)	109.31	95.82	71.12	86.36	41.55	98.79	29.69	65.66
H_2S	1.50	1.50	0.47	0.70	0.34	1.68	2.61	1.06
N_2	1.41	1.41	1.12	1.24	4.13	0.90	0.69	1.58
H_2	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.09
Total	112.24	98.75	72.73	88.32	46.05	101.40	33.02	68.39
% in the steam	0.49	0.43	0.32	0.39	0.20	0.44	0.14	0.30
T Na/K Fournier (°C)	238	235	238	238	239	234	238	239
T Na/K/Ca (°C)	240	235	237	237	238	233	236	235
T quartz msl (°C)	239	246	243	240	243		251	
T measured (°C)	240		244		245		244	248
Depth (m)	840		867		882		882	882
Enthalpy (kJ/kg)	1081	1081	1143	1151	1087	1055	1055	1076

TABLE 4: Chemical composition of fluids of well PGM-03 with time, Miravalles geothermal field, Costa Rica

Date	Jun 94	Dec 94	Mar 95	Nov 95	Nov 96	Apr 97	May 97	Jun 97	Mar 98
P.sep. (bar a.)	0.94	0.94	0.94	0.94	0.94	0.94	0.94	6.94	5.70
pH	8.05	8.10	8.09	8.32	8.10	7.59	7.89	7.32	7.32
Cond. (µS/cm²)	12150	11640	11970	11900	12560	9760	12400	11000	10700
Na^+ (ppm)	2396	2413	2402	2373	2506	2443	2513	2130	2135
K^+	300	304	288	293	313	297	304	252	262
Ca^{+2}	66	69	67	69	70	96	96	67	67
Mg^{+2}	0.05	0.09	0.05	0.05	0.09	0.11	0.08	0.04	0.09
Li^+	5.17	6.19	6.28	5.98	5.67	5.79	5.73	4.76	5.15
Rb^+	0.98	0.96	0.98	0.96	0.89	0.93	0.91	0.80	0.72
Cs^+	0.67	0.65	0.59	0.52	0.62	0.64	0.55	0.52	0.49
$Al_{(tot.)}$	0.45	0.39	0.00	0.55	0.90		0.86		0.45
$Fe_{(tot.)}$	0.15	0.11	0.00	0.00	0.33			0.02	0.92
Cl^-	4000	4050	3969	4003	4115	4060	4174	3540	3555
$SO_4^=$	43	54	44	43	40	44	37	37	37
HCO_3^-	24	31	30	26	23	24	19	34	31
F^-	1.66	1.70	1.65	1.44	2.01	1.72	1.65	1.45	1.77
B	67	63	64	63	67	63	65	56	57
H_2S	0.57	0.05	1.99	1.96	3.52	1.03	2.86	0.52	0.49
NH_3	1.24	1.07	1.06	0.95	2.15	1.50	1.40	2.03	1.53
$As_{(tot.)}$	10.7	10.6	10.3	10.6	10.5	10.5	10.1	8.8	8.9
SiO_2	698	583	548	605	594	605	609	569	533
Ionic Balance	0.83	0.55	1.21	0.40	1.75	1.58	1.67	0.98	1.09
TDS	8029	7992	7904	7900	8021	7955			6900
CO_2 (mmol/kg)	92.78	88.05	86.99	95.12	73.65	136.98	129.69	128.58	153.78
H_2S	1.29	0.93	1.86	0.65	0.51	1.93	1.40	0.93	2.46
N_2	3.28	2.47	1.97	1.86	3.65	6.32	5.84	4.58	7.15
H_2	0.01	0.11	0.01	0.01	0.04	0.03	0.03	0.04	0.06
Total	97.36	91.56	90.83	97.64	77.85	145.26	136.96	134.13	163.45
% in the steam	0.42	0.40	0.39	0.43	0.34	0.63	0.59	0.58	0.71
T Na/K Fournier (°C)	237	237	233	236	237	234	234	232	235
T Na-K-Ca (°C)	236	236	233	234	236	230	230	229	232
T quartz msl. (°C)	251	237	232	240	238	240	240	235	230
T measured (°C)	241	241	239		235		237		
Depth (m)	690	690	690		690		690		
Enthalpy (kJ/kg)	1043	1053	1120	1161	1126	1085	1085	1085	1143

TABLE 5: Chemical composition of fluids of well PGM-05 with time, Miravalles geothermal field, Costa Rica

Date	Jun 94	Oct 94	Mar 95	Nov 96	Jun 97	Aug 97	Mar 98
P.sep. (bar a.)	0.94	0.94	0.94	0.94	11.23	0.94	9.60
pH	8.15	8.06	8.16	8.07	6.82	7.94	6.50
Cond. (µS/cm²)	11650	12350	12490	12730	11200	13750	11450
Na^+ (ppm)	2307	2249	2448	2566	2140	2675	2147
K^+	285	276	290	321	253	326	261
Ca^{+2}	75	81	87	104	90	117	92
Mg^{+2}	0.17	0.09	0.06	0.07	0.66	0.12	0.12
Li^+	5.36	6.01	6.29	5.43	4.42	5.42	4.75
Rb^+	0.99	0.95	1.13	1.01	0.84	1.03	0.74
Cs^+	0.66	0.68	0.55	0.64	0.50	0.64	0.47
$Al_{(tot.)}$	0.42	0.59	0.62	0.51		1.01	0.64
$Fe_{(tot.)}$	0.09	0.05		0.16			0.04
Cl^-	3861	3845	4113	4331	3590	4570	3585
$SO_4^=$	47	34	44	43	41	49	36
HCO_3^-	22	27	24	14	41	12	46
F^-	1.54	1.50	1.50	1.70	1.39	1.85	1.46
B	59	63	63	67	56	70	55
H_2S	0.52	0.30	1.22	7.11	1.00	0.99	1.55
NH_3	0.30	0.67	0.55	0.78		0.91	1.59
$As_{(tot.)}$	10.1	9.7	9.1	10.8	8.2	11.2	8.4
SiO_2	608	562	586	568	519	548	478
Ionic Balance	0.89	0.16	0.83	1.05	0.97	0.51	1.37
TDS	7777	7710	7924	8421		8785	6900
CO_2 (mmol/kg)	105.77	96.49	77.74	78.69	165.50	70.29	122.11
H_2S	0.58	0.35	0.84	0.56	2.30	1.64	2.01
N_2	1.46	2.16	0.76	1.58	2.76	1.72	2.39
H_2	0.01	0.04	0.02	0.03	0.06	0.03	0.05
Total	107.82	99.04	79.36	80.86	170.62	73.68	126.56
% in the steam	0.47	0.43	0.35	0.35	0.74	0.32	0.55
T Na/K Fournier (°C)	236	235	232	237	232	235	234
T Na/K/Ca (°C)	233	231	230	232	226	230	228
T quartz msl (°C)	240	234	237	235		232	
T measured (°C)	238.0	239.5	239.1	241.7		239.0	
Depth (m)	1400	1505	1285	1385		1505	
Enthalpy (kJ/kg)	1085	1079	1084	1034	1034	1072	1072

TABLE 6: Chemical composition of fluids of well PGM-10 with time, Miravalles geothermal field, Costa Rica

Date	Jun 94	Oct 94	Feb 95	Nov 95	Dec 96	Jun 97	Aug 97	Mar 98
P.sep. (bar a.)	0.94	0.94	0.94	0.94	0.94	7.61	0.94	6.10
pH	8.09	8.08	8.14	8.22	8.12	7.23	7.90	7.28
Cond. (μS/cm²)	11520	12000	12375	12750	12700	11400	13100	10700
Na^+ (ppm)	2352	2259	2386	2515	2568	2160	2546	2016
K^+	299	281	297	313	328	265	319	248
Ca^{+2}	74	75	77	81	85	78	94	76
Mg^{+2}	0.06	0.05	0.03	0.03	0.02	0.03	0.08	0.23
Li^+	5.57	6.07	6.11	5.92	5.52	4.72	5.58	4.64
Rb^+	1.00	0.98	0.99	1.04	0.96	0.85	1.00	0.70
Cs^+	0.67	0.64	0.74	0.57	0.61	0.51	0.62	0.44
$Al_{(tot.)}$	0.36	0.52	0.43	0.54	1.37		1.04	0.44
$Fe_{(tot.)}$	0.05	0.05	0.08	0.00	0.15	0.03		0.13
Cl^-	3941	3866	4014	4274	4331	3640	4355	3380
$SO_4^=$	47	50	42	40	35	32	46	34
HCO_3^-	24	27	23	11	7	32	14.30	32.00
F^-	2.00	1.42	1.41	1.86	2.21	1.45	1.90	1.49
B	61.99	66.36	61.71	65.83	65.20	57.00	68	52
H_2S	0.13	0.45	0.00	0.73	2.09	1.00	1.01	2.78
NH_3	0.81	0.55	0.55	0.57	0.82	1.79	1.63	1.37
$As_{(tot.)}$	10.38	10.38	10.35	10.28	10.30	8.84	10.6	8.4
SiO_2	565	579	579	634	625	550	594	474
Ionic Balance	0.88	-0.16	0.76	0.35	0.94	0.71	0.21	1.04
TDS	8614	7909	7803	8405	8372		8390	6600
CO_2 (mmol/kg)	103.26	106.42	67.13	60.94	64.93	86.32	62.36	141.44
H_2S (mmol/kg)	0.82	2.01	0.52	0.55	0.46	1.40	1.32	1.99
N_2 (mmol/kg)	1.41	1.42	1.28	0.64	1.22	1.13	1.02	3.33
H_2 (mmol/kg)	0.02	0.08	0.00	0.03	0.03	0.07	0.06	0.16
Total	105.51	109.93	68.93	62.16	66.64	88.92	64.76	146.92
% in the steam	0.46	0.48	0.30	0.27	0.29	0.39	0.28	0.64
T Na/K Fournier (°C)	238	236	237	236	239	235	237	235
T Na/K/Ca (°C)	235	233	234	234	236	230	233	229
T quartz msl. (°C)	235	236	236	243	242		238	
T measured (°C)	236.8		232.9		228.7		238.7	
Depth (m)	1052		1252		1302		1352	
Enthalpy (kJ/kg)	1172	1086	1118	1148	1084		1029	

TABLE 7: Chemical composition of fluids of well PGM-11 with time, Miravalles geothermal field, Costa Rica

Date	Jun 94	Nov 94	Mar 95	Nov 96	Jun 97	Aug 97	Mar 98
P.sep. (bar a.)	0.94	0.94	0.94	0.94	9.64	0.94	8.20
pH	8.11	8.17	8.12	8.21	6.98	7.97	7.18
Cond. (µS/cm²)	12300	12583	12620	12230	10600	12925	10200
Na^+ (ppm)	2433	2333	2495	2485	2060	2464	2035
K^+	293	269	294	301	232	288	237
Ca^{+2}	60	64	60	62	56	67	57
Mg^{+2}	0.06	0.11	0.07	0.07	0.05	0.06	0.08
Li^+	5.41	6.37	6.69	5.93	4.84	6.15	5.47
Rb^+	0.95	0.86	0.99	0.84	0.75	0.87	0.63
Cs^+	0.65	0.59	0.59	0.67	0.52	0.55	0.41
$Al_{(tot.)}$	0.48	0.50	0.84	0.66			0.34
$Fe_{(tot.)}$	0.15	0.06	0.00	0.07	0.09		0.11
Cl^-	4059	3914	4098	4099	3370	4115	3370
$SO_4^=$	38	45	44	38	32	34	38
HCO_3^-	34	48	38	44	74	45	74
F^-	1.66	1.47	1.56	1.84	1.29	1.70	1.43
B	68	62	64	65	54	57	53
H_2S	1.07	0.20	1.22	4.79	0.69	0.89	0.74
NH_3	1.18	1.02	0.98	1.61	1.65	0.79	1.64
$As_{(tot.)}$	10.6	11.0	11.0	10.1	8.2	10.1	7.9
SiO_2	660	648	661	645	587	721	541
Ionic Balance	0.58	0.21	1.28	1.15	1.10	0.56	0.63
TDS	8515	8069	7939	8087		8025	6635
CO_2 (mmol/kg)	171.77	138.13	165.92	173.17	405.69	322.45	306.89
H_2S (mmol/kg)	1.39	0.30	1.20	0.78	2.04	4.78	2.05
N_2 (mmol/kg)	1.37	2.43	0.87	1.50	2.12	1.95	1.59
H_2 (mmol/kg)	0.01	0.02	0.02	0.04	0.10	0.07	0.10
Total	174.54	140.88	168.01	175.49	409.95	329.25	310.63
% in the steam	0.76	0.62	0.74	0.77	1.80	1.44	1.36
T Na/K Fournier (°C)	233	230	231	234	227	231	230
T Na/K/Ca (°C)	235	230	234	235	227	232	229
T quartz msl. (°C)	246	245	246	244		253	
T measured (°C)	244.0		247.5	244.2		246.2	
Depth (m)	1012		837	1119		1019	
Enthalpy (kJ/kg)	1127	1071	1100	1056		1075	

TABLE 8: Chemical composition of fluids of well PGM-12 with time, Miravalles geothermal field, Costa Rica

Date	Mar 94	Aug 94	Feb 95	Nov 95	Jun 97	Mar 98
P.sep. (bar a.)	0.94	0.94	0.94	0.94	7.34	7.44
pH	8.14	8.15	8.14	8.04	7.92	5.69
Cond. (μS/cm²)	11900	11882	12580	12700	11800	11950
Na^+ (ppm)	2326	2298	2446	2519	2330	2196
K^+	298	279	299	282	272	264
Ca^{+2}	68	67	71	82	80	79
Mg^{+2}	0.28	0.37	0.30	0.27	0.15	0.12
Li^+	5.57	5.97	5.90	6.07	4.50	4.66
Rb^+	0.98	0.91	0.96	0.97	0.85	0.72
Cs^+	0.64	0.70	0.62	0.67	0.58	0.49
$Al_{(tot.)}$	0.54	0.39	0.43	0.62		0.35
$Fe_{(tot.)}$	0.05	0.07	0.22	0.00	0.04	0.96
Cl^-	3920	3885	4110	4238	3860	3615
$SO_4^=$	87	52	66	58	52	44
HCO_3^-	110	34	29	22	16	49
F^-	1.48	1.25	1.40	1.69	1.62	1.74
B	62	65	64	66	60	57
H_2S	0.16	0.31	0.25	6.48	1.03	2.29
NH_3	2.90	1.96	1.62	1.44	2.52	2.62
$As_{(tot.)}$	10.5	10.58	10.69	10.63	9.26	8.76
SiO_2	552	562	517	551	518	440
Ionic Balance	-0.46	0.10	0.34	0.33	1.25	1.58
TDS	7740	8205	7872	8266		7070
CO_2 (mmol/kg)	100.99	109.49	81.21	64.35	121.15	70.21
H_2S (mmol/kg)	0.09	0.97	0.42	1.69	1.43	1.25
N_2 (mmol/kg)	3.32	2.04	1.49	0.86	2.05	1.22
H_2 (mmol/kg)	0.01	0.01	0.00	0.02	0.10	0.14
Total	104.41	112.51	83.12	66.92	124.73	72.82
% in the steam	0.45	0.49	0.36	0.29	0.54	0.32
T Na/K Fournier (°C)	239	234	235	227	231	233
T Na/K/Ca (°C)	236	233	234	227	228	229
T quartz msl. (°C)	233	234	228	233		
T measured (°C)		227	229	235		
Depth (m)		841	841	1000		
Enthalpy (kJ/kg)	1044	1041	1039	1065		

TABLE 9: Chemical composition of fluids of well PGM-17 with time, Miravalles geothermal field, Costa Rica

Date	Jun 94	Dec 94	Mar 95	Jan 97	Jun 97	Mar 98
P.sep. (bar a.)	0.94	0.94	0.94	0.94	7.34	6.20
pH	8.20	8.14	8.14	8.02	7.22	7.49
Cond. (μS/cm²)	12671	11730	11970	12550	11000	10700
Na^+ (ppm)	2444	2393	2441	2458	2100	2138
K^+	304	305	287	309	250	264
Ca^{+2}	65	67	64	71	60	63
Mg^{+2}	0.05	0.10	0.06	0.07	0.05	0.07
Li^+	5.18	6.29	6.39	6.17	5.18	5.35
Rb^+	0.97	0.96	0.96	1.05	0.75	0.71
Cs^+	0.66	0.65	0.60	0.72	0.52	0.49
$Al_{(tot.)}$	0.50	0.41	0.27	0.00		0.37
$Fe_{(tot.)}$	0.14	0.10	0.00	0.09	0.03	0.08
Cl^-	3981	4025	4063	4122	3550	3525
$SO_4^=$	46	60	49	45	36	37
HCO_3^-	20	40	36	32	49	52
F^-	1.72	1.69	1.61	1.77	1.39	1.57
B	66.06	63.82	64.10	65.50	57.00	57
H_2S	0.63	0.05	1.95	1.22	0.69	0.66
NH_3	1.35	1.13	1.28	1.53	2.55	2.29
$As_{(tot.)}$	10.44	10.64	0.00	10.23	8.89	9.0
SiO_2	604	597	591	552	556	523
Ionic Balance	1.99	0.36	0.66	0.67	-0.07	1.32
TDS	8246	7915	7877	8138		6935
CO_2 (mmol/kg)	122.45	83.50	72.23	85.32	165.36	159.26
H_2S (mmol/kg)	1.31	0.48	1.05	0.91	1.97	2.06
N_2 (mmol/kg)	2.38	2.02	1.22	1.48	2.08	2.66
H_2 (mmol/kg)	0.01	0.06	0.01	0.08	0.02	0.16
Total	126.15	86.06	74.51	87.79	169.43	164.14
% in the steam	0.55	0.37	0.32	0.38	0.74	0.72
T Na/K Fournier (°C)	237	239	231	237	232	236
T Na/K/Ca	236	237	232	236	231	233
T quartz msl. (°C)	239	239	238	233		
T measured (°C)	240	235	240	240		
Depth (m)	1046	1046	973	1123		
Enthalpy (kJ/kg)	1036	1013	1036	1038		

TABLE 10: Chemical composition of fluids of well PGM-20 with time, Miravalles geothermal field, Costa Rica

Date	Aug 94	Mar 95	Nov 95	Dec 96	Jun 97	Nov 97	Jan 98
P.sep. (bar a.)	0.94	0.94	0.94	0.94	8.44	0.94	6.60
pH	8.07	8.18	8.09	7.89	7.37	8.02	7.82
Cond. (µS/cm²)	12018	12070	12100	12250	11000	13225	11500
Na^+ (ppm)	2305	2391	2388	2463	2130	2485	2176
K^+	267	289	271	309	247	308	266
Ca^{+2}	72	77	82	85	76	102	82
Mg^{+2}	0.14	0.09	0.06	0.08	0.10	0.09	0.10
Li^+	6.02	5.95	5.89	5.47	5.26	8.24	4.63
Rb^+	0.90	0.96	0.91	1.08	0.88	1.59	0.74
Cs^+	0.66	0.76	1.09	0.53	0.60	0.60	0.49
$Al_{(tot.)}$	0.52	0.61	0.61	1.48		0.34	1.20
$Fe_{(tot.)}$	0.08	0.49	0.00	0.00	0.02		
Cl^-	3861	3992	4050	4102	3520	4325	3690
$SO_4^=$	62	46	53	52	46	40	53
HCO_3^-	27	26	21	27	38	23	34
F^-	1.54	1.59	1.69	1.72	1.45	1.79	1.72
B	63.49	62.50	63.00	61.90	55.00	82.63	57.00
H_2S	0.47	0.00	3.73	0.80	0.69	1.46	0.50
NH_3	1.29	0.87	1.05	3.17	2.17	1.17	1.75
$As_{(tot.)}$	10.40	10.51	9.78	9.30	8.11	10.58	7.80
SiO_2	579	613	567	578	518	566	495
Ionic Balance	0.47	0.98	0.07	1.29	1.32	-0.37	0.31
TDS	8014	7761	7893	8112		8358	7130
CO_2 (mmol/kg)	108.21	88.26	53.40	53.73	103.53	69.86	87.17
9.00	1.27	0.40	1.33	0.33	1.40	1.36	2.07
N_2 (mmol/kg)	2.44	2.94	3.96	6.20	13.07	6.69	8.92
H_2 (mmol/kg)	0.01	0.01	0.02	0.02	0.02	0.04	0.04
Total	111.93	91.61	58.71	60.28	118.02	77.95	98.20
% in the steam	0.49	0.40	0.25	0.25	0.50	0.33	0.42
T Na/K Fournier (°C)	230	234	228	237	230	236	235
T Na/K/Ca (°C)	229	232	227	234	226	231	230
T quartz msl. (°C)	236	241	235	236		235	
T measured (°C)	232	232				237	
Depth (m)	790	790				817	
Enthalpy (kJ/kg)	999	999	999	999		1024	

TABLE 11: Chemical composition of fluids of well PGM-21 with time, Miravalles geothermal field, Costa Rica

Date	Sep 94	Jan 95	Nov 95	Aug 96	Dec 96	Jun 98	Mar 98
P.sep. (bar a.)	0.94	0.94	0.94	0.94	0.94	9.94	7.20
pH	8.23	8.19	8.23	8.09	8.14	7.30	7.67
Cond. (µS/cm²)	12510	11810	12325	12390	11850	10900	10500
Na^+ (ppm)	2391	2453	2453	2444	2503	2130	2161
K^+	273	292	262	296	288	242	253
Ca^{+2}	67	76	76	74	75	70	74
Mg^{+2}	0.01	0.13	0.09	0.15	0.11	0.08	0.40
Li^+	6.03	6.16	6.09	5.74	5.78	4.61	5.18
Rb^+	0.90	0.91	0.91	0.84	1.03	0.78	0.68
Cs^+	0.62	0.63	0.69	0.56	0.56	0.55	0.49
$Al_{(tot.)}$	0.41	0.42	0.54	0.00	1.29		0.42
$Fe_{(tot.)}$	0.09	0.09	0.00	0.13	0.18	0.16	0.09
Cl^-	3981	4129	4072	4212	4124	3480	3578
$SO_4^=$	51	72	58	52	52	46	42
HCO_3^-	32	42	38	32	30	64	53
F^-	1.67	1.74	1.70	0.00	1.59		1.44
B	65	63	66	66	61	56	57
H_2S	0.46	0.30	2.33	0.63	1.72	0.69	1.31
NH_3	0.87	0.58	1.30	2.77	1.47	2.94	2.18
$As_{(tot.)}$	10.8	10.9	10.5	9.4	10.2	8.6	8.7
SiO_2	567	534	546	556	576	513	493
Ionic Balance	0.61	0.12	0.62	-0.78	1.32	1.46	1.14
TDS	8168	7978	7963	8141	8052		6920
CO_2 (mmol/kg)	130.72	120.69	111.90	90.41	127.89	302.79	210.07
H_2S (mmol/kg)	0.08	0.92	1.06	0.37	0.47	1.96	2.13
N_2 (mmol/kg)	4.01	2.28	1.63	1.94	1.88	3.03	2.67
H_2 (mmol/kg)	0.04	0.04	0.01	0.06	0.01	0.02	0.10
Total	134.85	123.93	114.60	92.78	130.25	307.80	214.97
% in the steam	0.59	0.54	0.50	0.40	0.57	1.35	0.94
T Na/K Fournier (°C)	229	233	223	234	229	228	231
T Na/K/Ca (°C)	229	232	224	233	230	226	228
T quartz msl. (°C)	235	230	232	233	236		
T measured (°C)	231	233			236		
Depth (m)	1650	1100			1653		
Enthalpy (kJ/kg)	991	999	1003		1087		

TABLE 12: Chemical composition of fluids of well PGM-31 with time, Miravalles geothermal field, Costa Rica

Date	Apr 94	Sep 94	Mar 95	Nov 95	Nov 96	Jun 97	Aug 97	Mar 98
P.sep. (bar a.)	0.94	0.94	0.94	0.94	0.94	7.41	0.94	5.65
pH	8.11	8.04	8.14	8.26	8.34	7.52	8.04	7.39
Cond. (µS/cm²)	12014	11207	11720	11800	12080	1100	12575	11400
Na^+ (ppm)	2168	2228	2355	2311	2434	2120	2434	2146
K^+	275	269	282	265	304	249	301	259
Ca^{+2}	66	59	72	77	80	73	89	77
Mg^{+2}	0.09	0.08	0.06	0.08	0.19	0.08	0.18	0.16
Li^+	5.55	5.77	6.23	6.15	5.53	4.92	5.57	5.19
Rb^+	0.89	0.89	0.88	0.94	0.92	0.80	0.93	0.72
Cs^+	0.64	0.65	0.65	0.64	0.57	0.50	0.60	0.49
$Al_{(tot.)}$	0.40	0.38	0.54		0.50		0.97	0.33
$Fe_{(tot.)}$	0.14	0.10	0.00	0.00	0.00	0.03	0.00	0.10
Cl^-	3844	3805	3978	3991	4064	3540	4155	3560
$SO_4^=$	51	59	59	48	47	43	43	37
HCO_3^-	25	24	31	31	24	35	21	43
F^-	1.41	1.61	1.56	1.50	1.93	1.34	1.80	1.54
B	62	61	61	63	62	55	60	55
H_2S	0.24	0.15	2.24	3.84	2.41	0.69	0.77	1.15
NH_3	0.95	0.87	0.73	0.42	0.82	1.93	0.95	2.10
$As_{(tot.)}$	9.6	9.9	10.5	10.6	10.4	8.6	10.3	9.1
SiO_2	587	565	572	568	579	541	563	510
Ionic Balance	-2.02	-0.57	0.15	-0.87	1.10	0.82	0.22	1.34
TDS	7879	7617	7650	7605	8013		8045	6905
CO_2 (mmol/kg)	113.20	68.11	71.94	86.71	58.02	180.38	39.13	95.71
H_2S (mmol/kg)	0.78	0.06	0.64	0.57	0.41	2.17	0.77	1.15
N_2 (mmol/kg)	9.98	10.23	2.41	1.74	1.24	2.29	0.95	1.03
H_2 (mmol/kg)	0.01	0.15	0.02	0.01	0.02	0.02	0.01	0.06
Total	123.97	78.55	75.01	89.03	59.69	184.86	40.86	97.95
% in the steam	0.53	0.33	0.33	0.39	0.26	0.81	0.18	0.43
T Na/K Fournier (°C)	238	234	233	229	237	231	236	234
T Na/K/Ca (°C)	234	233	231	227	234	228	232	229
T quartz msl. (°C)	237	235	235	235	236		234	
T measured (°C)		237	236		238		239	
Depth (m)		900	850		850		793	
Enthalpy (kJ/kg)		1008	1016	1007	1024		1032	

TABLE 13: Chemical composition of fluids of well PGM-45 withe time, Miravalles geothermal field, Costa Rica

Date	Mar 95	Aug 96	Feb 97	Jan 98
P.sep. (bar a.)	0.94	0.94	0.94	8.20
pH	8.06	8.04	7.91	7.47
Cond. (µS/cm²)	12150	12386	12700	11100
Na^+ (ppm)	2372	2536	2469	2096
K^+	308	324	323	268
Ca^{+2}	66	72	75	63
Mg^{+2}	0.07	0.05	0.05	0.04
Li^+	6.34	6.08	6.08	4.81
Rb^+	0.81	0.91	1.29	0.76
Cs^+	0.56	0.57	0.77	0.47
$Al_{(tot.)}$	0.59	0.74		0.64
$Fe_{(tot.)}$	0.01	0.00	0.07	
Cl^-	3945	4195	4199	3530
$SO_4^=$	46	39	40	44
HCO_3^-	20	22	19	41
F^-	1.59	0.00	1.59	1.72
B	61	65	67	55
H_2S	1.47	0.49	0.20	0.30
NH_3	0.81	1.11	0.97	1.24
$As_{(tot.)}$	0.00	10.12	10.36	8.44
SiO_2	644	629	621	530
Ionic Balance	1.23	1.57	0.33	0.40
TDS	7743	8182	8281	6880
CO_2 (mmol/kg)	77.41	61.27	59.63	62.42
H_2S (mmol/kg)	1.33	0.88	1.94	1.33
N_2 (mmol/kg)	23.79	3.72	2.76	1.40
H_2 (mmol/kg)	0.00	0.06	0.02	0.06
Total	102.53	65.93	64.35	65.21
% in the steam	0.41	0.28	0.28	0.28
T Na/K Fournier (°C)	240	239	241	239
T Na/K/Ca (°C).	238	237	238	235
T quartz msl. (°C)	244	243	242	
T measured (°C)	239	241	243	
Depth (m)	700	675	700	
Enthalpy (kJ/kg)			1049	

TABLE 14: Chemical composition of fluids of well PGM-46 with time, Miravalles geothermal field, Costa Rica

Date	Feb 94	Sep 94	Dec 95	Feb 97	Jun 97
P.sep. (bar a.)	0.94	0.94	0.94	0.94	7.94
pH	8.06	8.06	8.27	7.80	7.19
Cond. (µS/cm²)	12400	12117	12100	13000	11200
Na^+ (ppm)	2324	2350	2318	2522	2140
K^+	297	286	275	321	259
Ca^{+2}	63	67	72	82	67
Mg^{+2}	0.69	0.17	0.10	0.08	0.04
Li^+	5.82	6.03	6.19	5.78	4.72
Rb^+	0.95	0.87	1.02	0.90	0.81
Cs^+	0.66	0.44	0.73	0.55	0.55
$Al_{(tot.)}$	0.76	0.63	0.00	0.00	
$Fe_{(tot.)}$	0.21	0.22		0.19	0.02
Cl^-	3943	3978	3944	4240	3550
$SO_4^=$	61	37	44	42	34
HCO_3^-	88	27	27	21	38
F^-	1.60	1.60	1.49	1.80	1.39
B	62.00	62.93	67.81	66.00	56.00
H_2S	0.15	2.26	1.99	2.92	0.52
NH_3	1.65	1.27	0.90	1.13	2.03
$As_{(tot.)}$	10.48	10.10	10.85	10.85	8.49
SiO_2	653	552	613	589	549
Ionic Balance	-0.46	0.21	-0.09	0.85	1.13
TDS	8243	7814	7960	8425	
CO_2 (mmol/kg)	98.90	58.90	56.02	37.76	103.26
H_2S (mmol/kg)	0.11	0.60	1.22	0.85	1.19
N_2 (mmol/kg)	7.37	2.06	2.04	1.33	5.00
H_2 (mmol/kg)	0.02	0.06	0.07	0.01	0.11
Total	106.40	61.62	59.35	39.95	109.56
% in the steam	0.46	0.27	0.26	0.17	0.47
T Na/K Fournier (°C)	239	234	232	239	234
T Na/K/Ca (°C)	237	233	230	236	231
T quartz msl (°C)	245	233	241	238	
T measured (°C)	235			241	
Depth (m)	1185			750	
Enthalpy (kJ/kg)	1003	1003	1026	1039	