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RESERVOIR CHANGES DURING EIGHTEEN YEARS OF EXPLOITATION IN THE MIRAVALLES GEOTHERMAL FIELD, COSTA RICA

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ABSTRACT

The Miravalles geothermal field has a liquid dominated two phase reservoir with temperatures of 220-250ºC. Miravalles started to operate in March 1994 with a 55 MWe power plant; nowadays, it produces a maximum of 150 MWe, using three condensing units (131 MWe), one back-pressure unit (5 MWe) and a binary plant (14 MWe). This production represents approximately a 12% of the total energy consumption of the country.

This report includes a brief description and analysis of the data related to the reservoir changes in Miravalles, obtained by the study of different methods. Data were obtained from pressure and temperature monitoring in production and observation wells, from output curves carried out in production wells and from seismic stations located in the zone.

Data analysis shows several changes registered at the reservoir as consequence of the extracted and injected masses in different zones of the field. Some of the most important variations are related with pressure, temperature, enthalpy and seismic activity:

1. INTRODUCTION

Costa Rica is located in the southern part of the Central American Isthmus. The Miravalles geothermal field is located in the southwestern side of the Miravalles volcano (Figure 1). Miravalles was the first field developed in the country, and was inaugurated in March 1994, and today is producing 150 MWe from a combination of three single flash units, a back-pressure unit and a binary power plant.

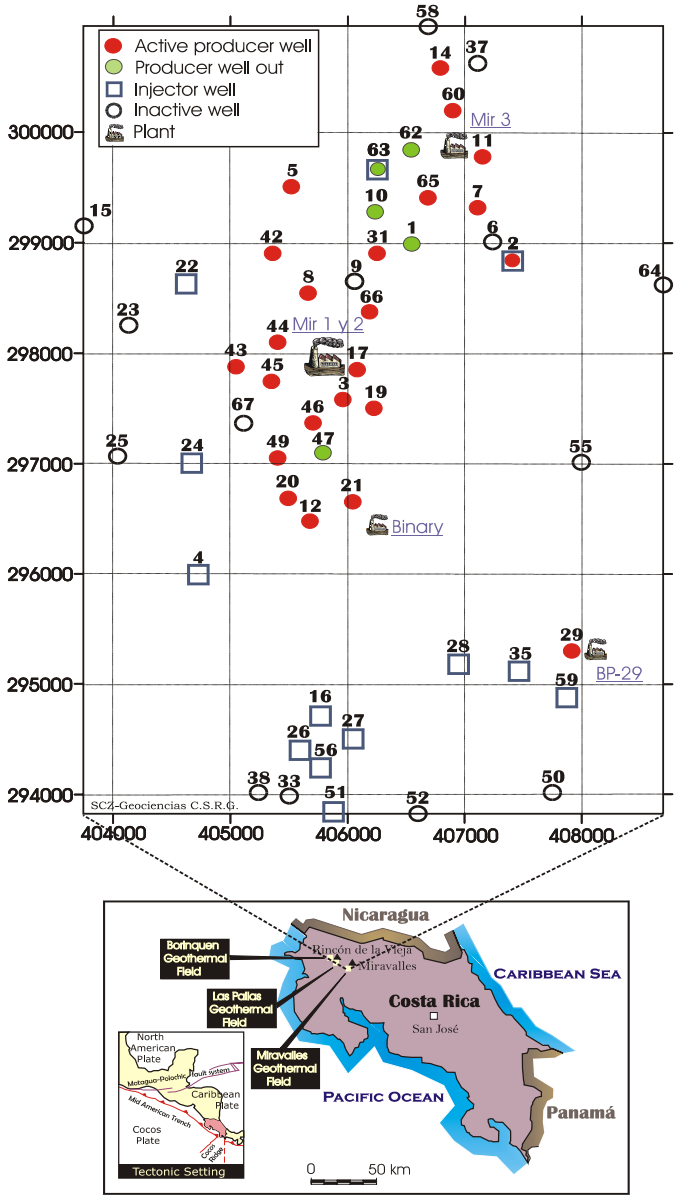

FIGURE 1: Tectonic setting, Costa Rica borders, location of the Guanacaste Geothermal Fields and location of the wells in the Miravalles Geothermal Field (modified from Chavarría, 2003)

After eighteen years of continuous operation, Miravalles has shown significant changes in some of the most representative parameters such as mass, temperature, pressure, enthalpy and seismicity, which have been collected by different methods and/or instruments that allow a analyzing trends in each case.

The calculation of the masses extracted and reinjected into the field was based on information gathered from separation units on the field and it was considered productive assessment conducted annually in each well. Furthermore, the reinjected flow is obtained by measuring the flow regularly sent to each reinjection well using calibrated flowmeters, or from injection curves made for that purpose.

The evolution of the reservoir properties such as temperature and pressure was monitored in the producing and observation wells using Kuster mechanical devices. Data were taken with a frequency of once or twice a year, while information from the producing wells were obtained annually through output tests using the Russel James method.

2. RESULTS

2.1 Extracted and injected mass

The total mass extracted and reinjected into Miravalles reservoir are presented in Figures 2 and 3. Analysis of data indicates that the difference between the sum of the two masses is 17%, this corresponds to the mass fraction of steam that was used to move the turbine at the different plants. Annual values indicate that between 1994 and 2003 occurred a steady increase in the masses used, whereas later, until 2010 flows tended to decrease and stabilize, and finally, for the last two years the masses have fallen substantially.

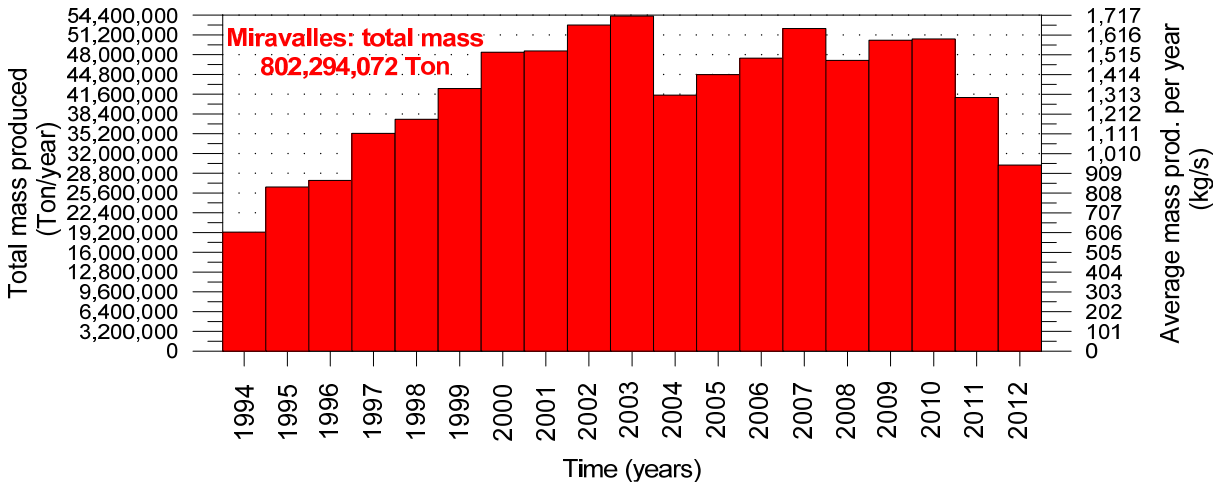

FIGURE 2: Total mass extracted in Miravalles during period 1994-2012

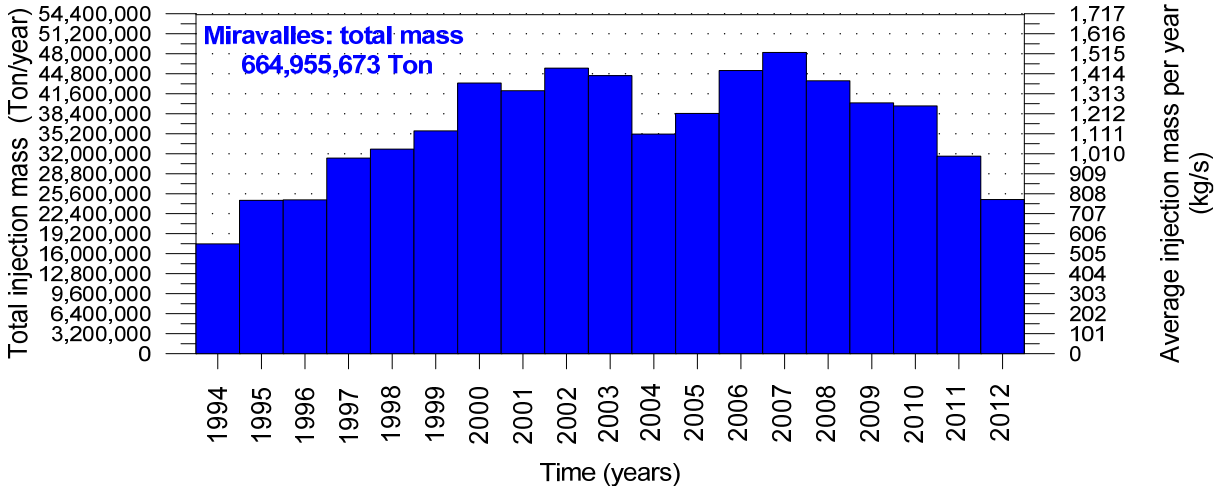

FIGURE 3: Total mass injected in Miravalles during period 1994-2012

Figure 4 shows a map of the masses that have been extracted and reinjected into all wells used in Miravalles. It is noted that the most important producing wells have been the PGM-21, PGM-45, PGM-46 and PGM-17, which provided more than 50 million tons each, while wells PGM-56, PGM-26, PGM-22 and PGM-24 have accepted more than 90 million tons each.

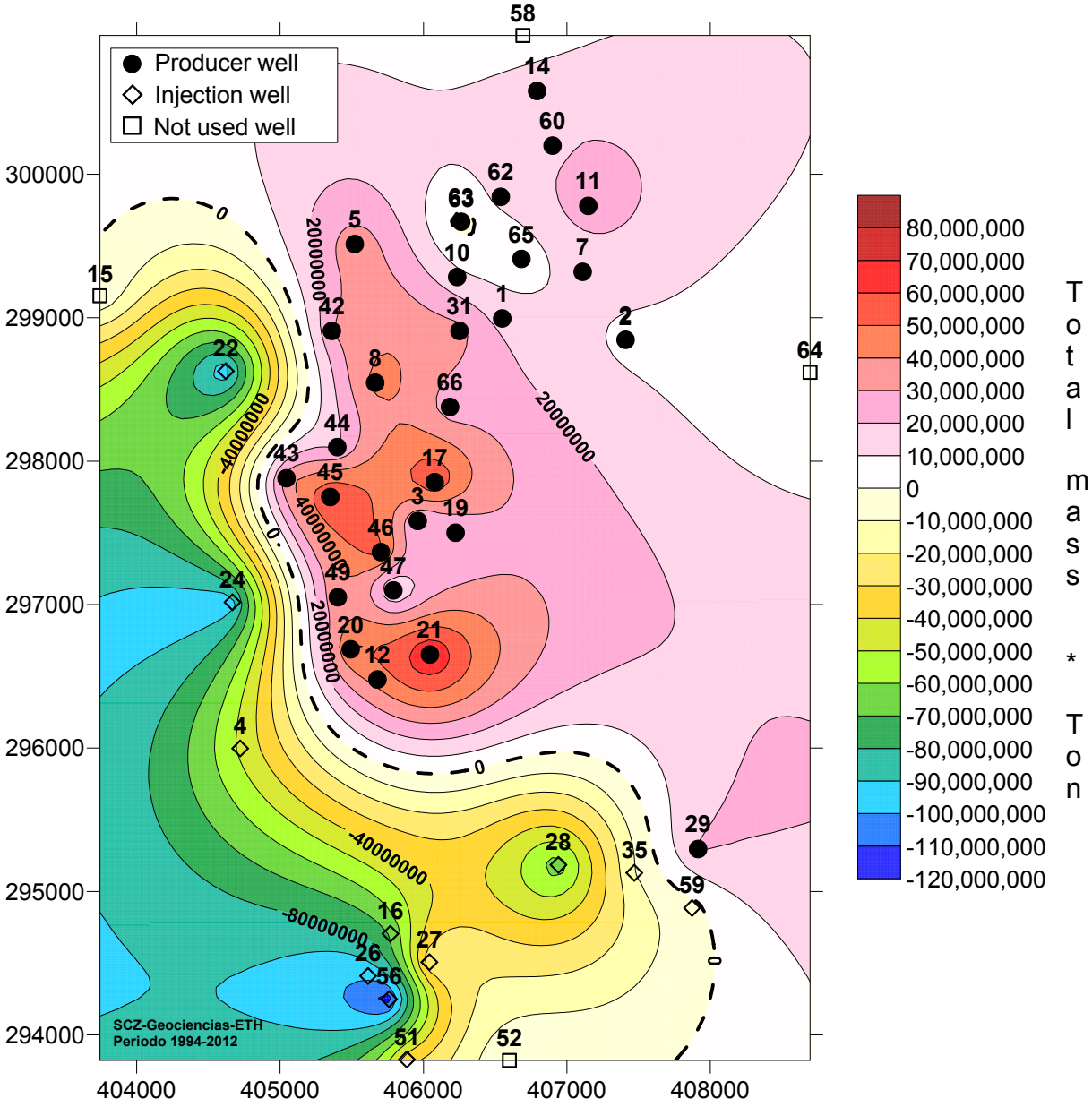

FIGURE 4: Total masses extracted and reinjected in Miravalles during period 1994-2012

2.2 Pressure behavior

Figure 5 shows the static pressure profiles of four producing wells that are located in different areas of the field. Included are profiles taken in the years 1994, 2004 and 2012, in order to observe the total fall during the 18 years of operation and also the difference in falls between the periods 1994-2004 and 2004-2012. The reduction in pressure drop between the two periods is due to both a reduction of the total mass extracted, as the increase of the vapor fraction obtained from the production wells.

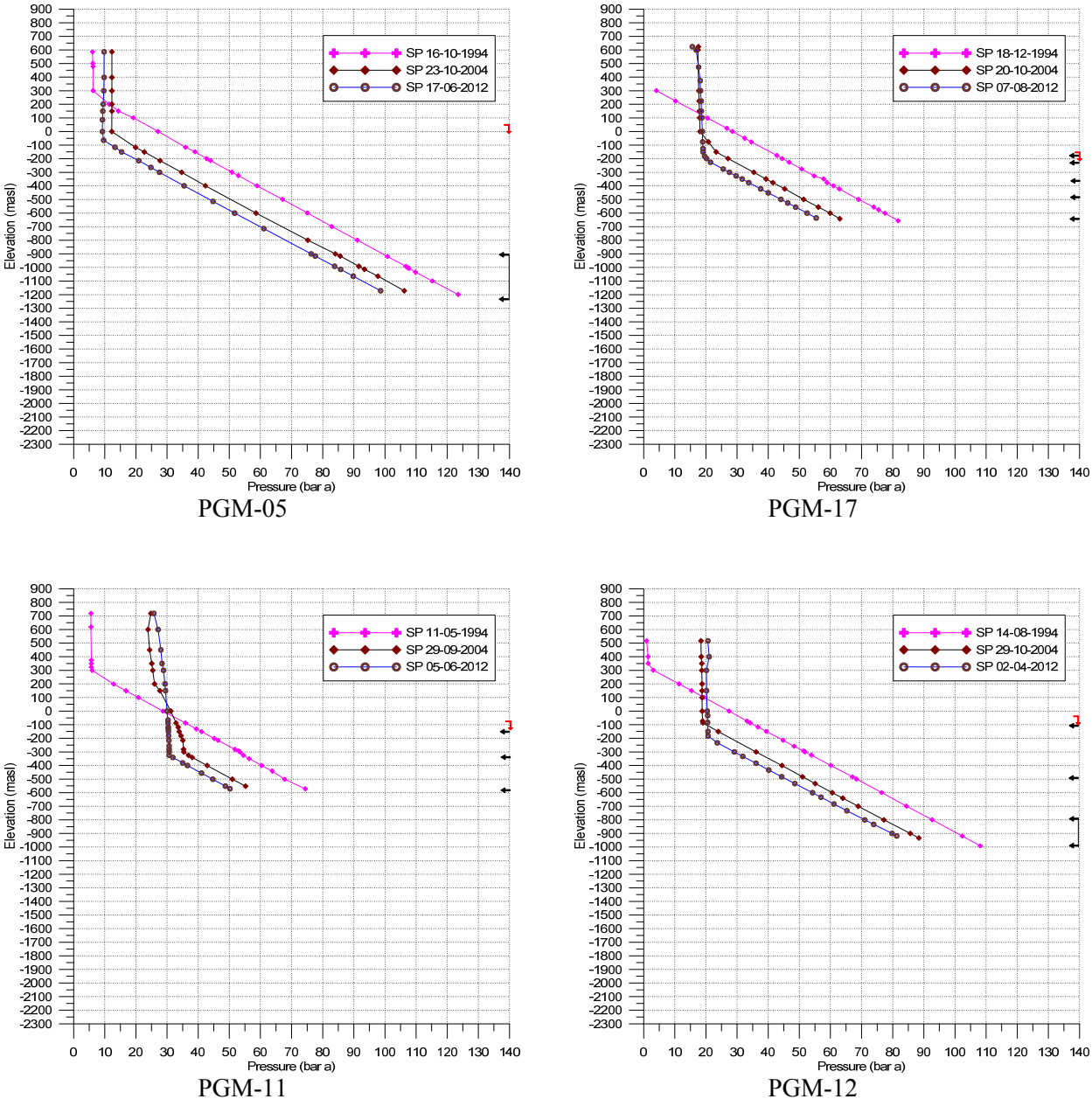

FIGURE 5: Static pressure profiles taken at PGM-05, PGM-11, PGM-12 and PGM-17

Table 1 shows the registered pressure values to the elevation indicated in each well available in 1994 and 2012. It is observed that the pressure drops ranged between 16.2 and 30.3 bars, with an average value of 23.7 bars. These data indicate that in Miravalles occurred an average drop of 1.3 bars per year, which means that the hydraulic level has dropped about 15 m per year.

TABLE 1: Total pressure decrease in the static profiles carried out in some wells of Miravalles

Well	Elevation measure (masl)	Pressure 1994 (bar a)	Pressure 2012 (bar a)	Pres. differ. 1994-2012 (bar a)
PGM01	-215	47.0	22.4	24.7
PGM05	-599	75.1	51.7	23.4
PGM08	-300	52.9	27.7	25.2
PGM09	-1059	114.7	89.9	24.8
PGM10	-700	89.4	59.1	30.3
PGM11	-400	60.4	36.6	23.8
PGM12	-799	92.6	71.0	21.6
PGM14	-97	35.9	10.9	25.0
PGM15	-1000	111.3	95.1	16.2
PGM17	-601	77.5	52.5	25.0
PGM20	-803	93.1	72.6	20.5
PGM21	-921	105.7	81.3	24.4
PGM25	-1543	159.4	134.4	25.0
PGM29	-726	86.3	65.8	20.5
PGM31	-500	69.5	44.8	24.7
PGM47	-694	84.8	63.2	21.6
PGM49	-601	78.7	53.0	25.7

Based on the data of the differential pressure column 1994-2012 of Table 1, was made the map presented in Figure 6, which shows that higher pressure drops are located in the north-central region of the field while the south and west have the lowest pressure drop.

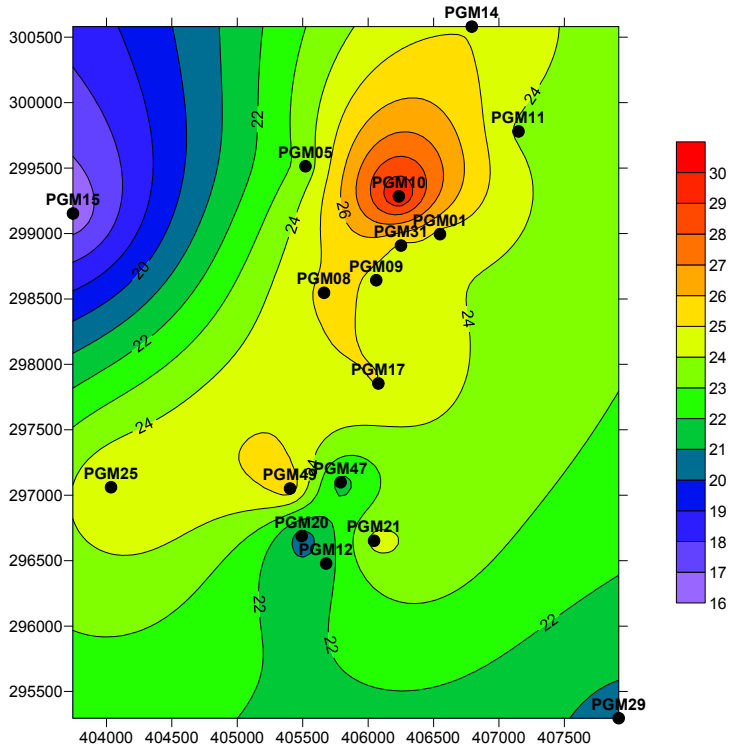

FIGURE 6: Static pressure decline in the period 1994-2012 in Miravalles

2.3 Temperature behavior

The dynamic temperature profiles of the four producers wells identified in the previous section are presented in Figure 7. Included are profiles taken in the years 1994, 2004 and 2012, in order to observe the trend that has presented this parameter in the periods indicated. It is noted that the temperature reduction has varied in each well described, being the PGM-12, the well has a greater cooling and which seems to indicate the influence of fluid reinjection, while in other cases, the behavior may indicate a loss of temperature related to the long period of operation of the wells.

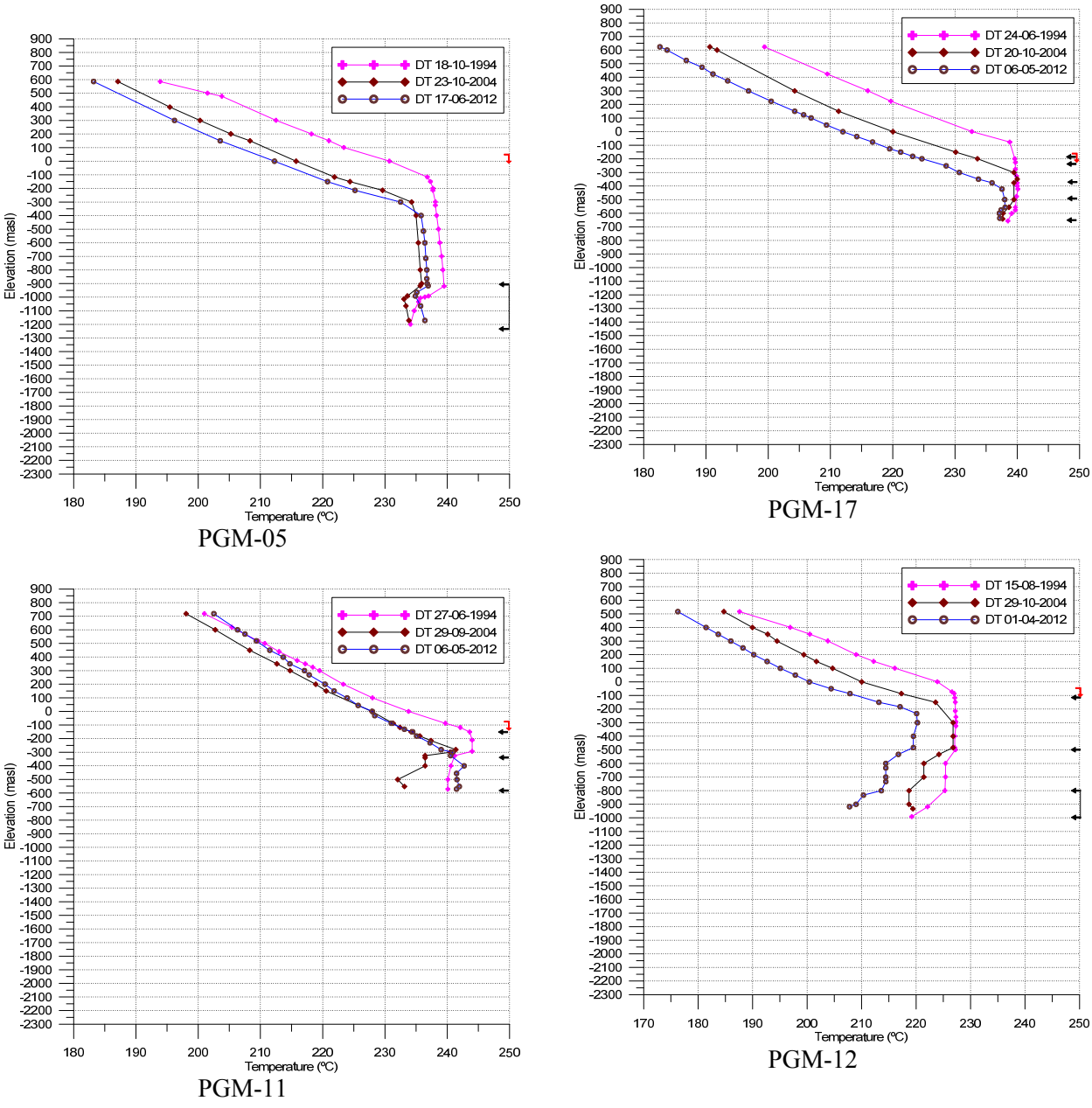

FIGURE 7: Dynamic temperature profiles carried out at wells PGM-05, PGM-11, PGM-12 and PGM-17

Table 2 shows the maximum values of the dynamic temperature recorded in nine wells in 1994 and 2012. Note that this parameter has a variable behavior, with wells that have experienced sharp declines (PGM-49 and PGM-12), others with small decreases (PGM-05, PGM-11 and PGM-17), while the rest wells have produced a slight increase in temperature of between 1 and 3 ° C.

TABLE 2: Temperature variation in dynamic profiles carried out in some wells of Miravalles

Well	Dynamic temperature		Temp. differ.
	1994 (°C)	2012 (°C)	1994-2012 (°C)
PGM05	239	237	-2
PGM11	244	243	-1
PGM12	227	220	-7
PGM17	240	238	-2
PGM20	232	233	1
PGM21	231	233	2
PGM29	230	233	3
PGM31	236	239	3
PGM49	232	206	-26

Based on the data of the column temperature difference recorded between 1994 and 2012 in Table 2, was made the map presented in Figure 6, showing the largest decreases in temperature are located in the western and south of the field, while in the central and northern areas the temperature has remained stable.

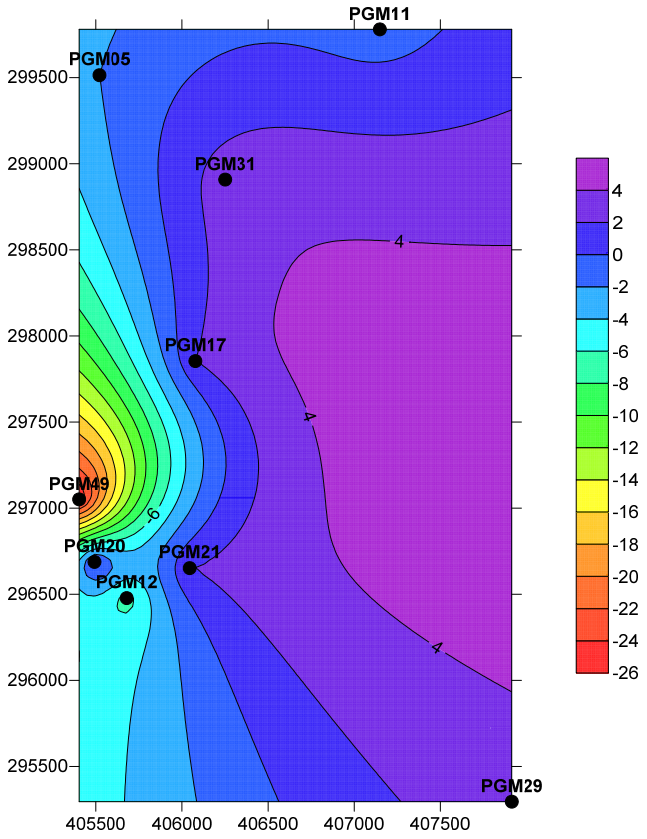

FIGURE 8: Variations in dynamic temperature in the period 1994-2012 in Miravalles

2.4 Enthalpy

Variations in the enthalpy of the fluid produced by the wells, indicates reservoir areas in which there has been an enrichment of steam and those that have been affected by low temperature aquifers, or, by the arrival of brine reinjection. Table 3 lists the values of enthalpy of wells with data from 1994 and 2012, and the fourth column shows the difference in enthalpy between the two years.

TABLE 3: Enthalpy variations in some wells of Miravalles

Well	Enthalpy		Enth. differ.
	1994	2012	1994-2012
	Max. Fl. (kJ/kg)	Max. Fl. (kJ/kg)	Max. Fl. (kJ/kg)
PGM02	955	1015	60
PGM03	1190	2007	817
PGM05	1104	1030	-74
PGM08	1030	1197	167
PGM10	1130	1512	382
PGM11	1145	1065	-80
PGM12	1043	944	-99
PGM14	1010	968	-42
PGM17	1025	1048	23
PGM19	1208	967	-241
PGM20	1130	1020	-110
PGM21	992	1000	8
PGM29	981	1105	124
PGM31	1008	1199	191
PGM45	1032	1788	756
PGM46	1009	969	-40

Enthalpy differences described in Table 3 were plotted on the map in Figure 9. The graph shows that the steam enriched zone is located in the central and north-central of the field, while the north and south have seen a reduction of the enthalpy of the fluid.

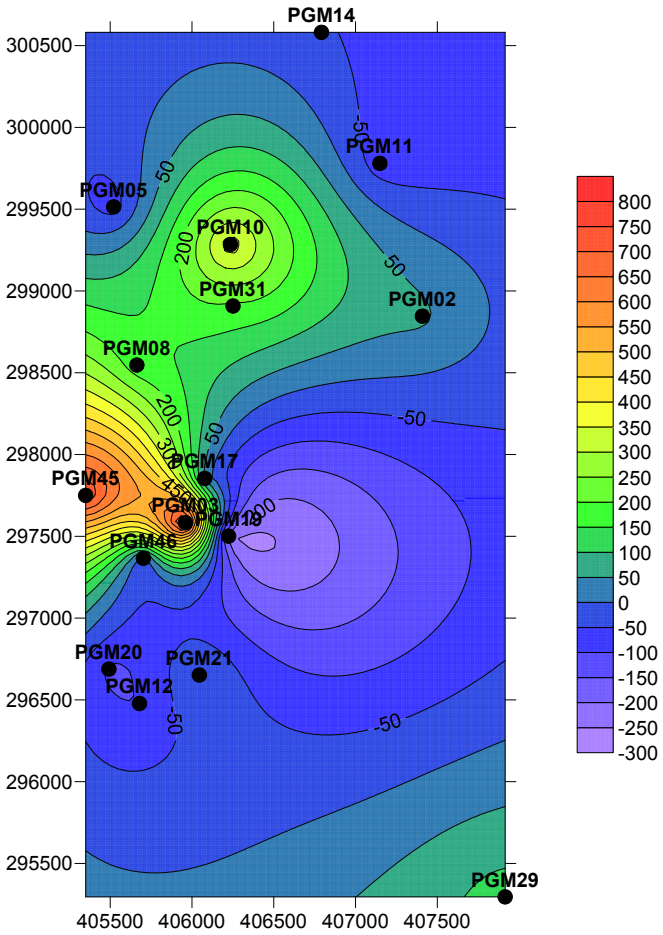

FIGURE 9: Variations in enthalpy in the period 1994-2012 in Miravalles

2.5 Seismic response to exploitation

Due to the large volumes that are mobilized in a geothermal reservoir in the process of exploitation, seismicity must be monitored to analyze the effects on the reservoir itself, and also from the social point of view, on the neighboring towns.
In Miravalles prior to start of operations in 1994, placed several seismic equipment that have provided detailed information on the frequency, magnitude and location of earthquakes.

Figure 10 shows the summary of the number of earthquakes recorded per year during the 18 years of operation of Miravalles. According to the number of earthquakes can define three periods:
- 1994-2000: the seismicity was very small
- 2001-2005: occurs a significant increase in seismicity
- 2006-2012: The number of earthquakes increases significantly

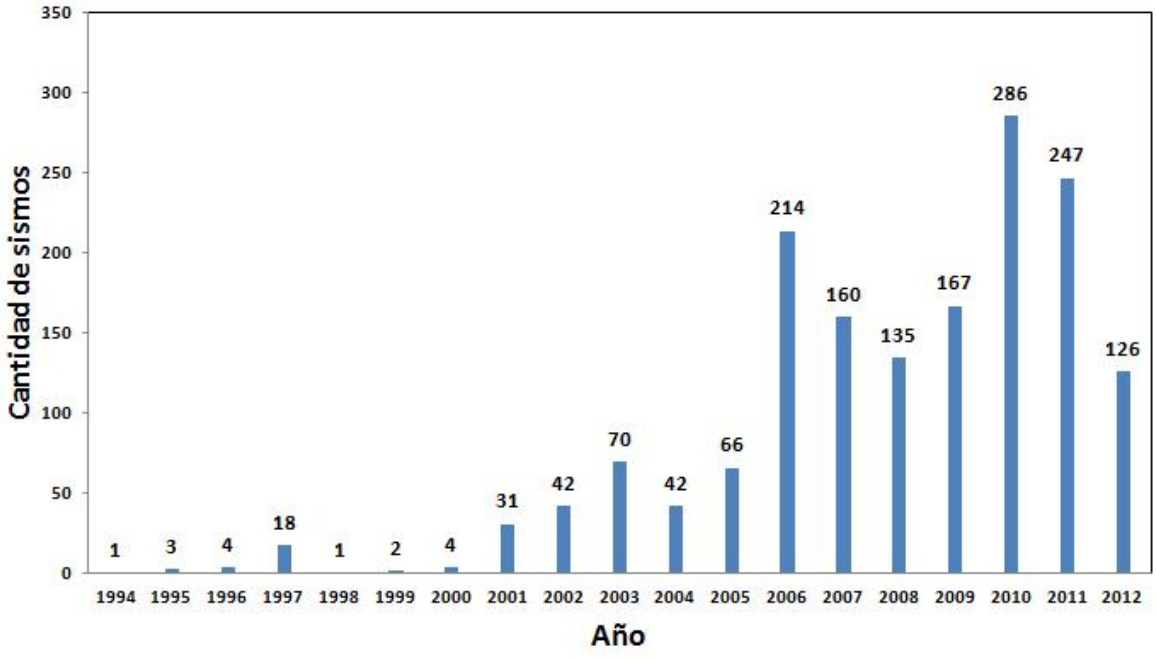

FIGURE 10: Seismic events registered per year in the period 1994-2012 in Miravalles

Figure 11 shows a map of the earthquakes recorded in Miravalles in 2011. It is observed that most seismic activity was located in the central and southern sectors of the field, but in the north also took a significant amount of earthquakes.

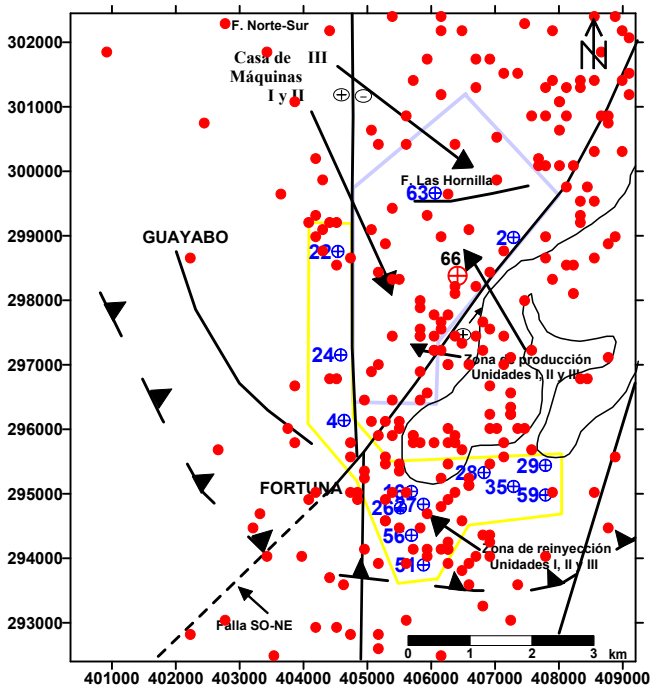

FIGURE 11: Map of seismic events registered in 2011 in Miravalles

3. CONCLUSIONS

Initially the Miravalles geothermal reservoir was a liquid dominant type with some isolated steam zones, which practically no were used in the first stage of field use. After 2000, when the three main plants of the field were incorporated and the amount of fluid extracted grew significantly, several wells showed positive anomalies of enthalpy and in some cases, became in steam producing wells. Furthermore, it has been observed that some wells located near reinjection zones, presented a reduction of the enthalpy confirming reinjected back flow towards the production zone.

Due to the massive extraction of geothermal fluid for 18 years of operation, the reservoir has presented a number of changes that have directly affected the policies of exploitation of the field. Some of the parameters have shown changes are:

-, Static pressure has dropped an average of 23 bars, which indicates that the hydraulic level is about 230 m depth from 1994.

- The dynamic temperature showed a variable behavior but tended to be very similar to that reported in 1994 (average variation + / - 5 °C), however, some wells near reinjection zones have shown a direct effect of these fluids which has caused a drop in temperature greater than 10 °C.

- Due to the hydraulic level abatement in reservoir and the consequent emergence of shallow steam zones in the central and north-central areas of the field, the enthalpies of several producing wells have increased significantly, while in the areas close to reinjection the enthalpies have fallen consistently.

- The recorded seismicity Miravalles area is directly related to the beginning of the exploitation of the reservoir in 1994. Since then the seismic activity has shown an increasing trend in both the number and the magnitude of the events recorded.

REFERENCES

Chavarría, L., 2003: Miravalles Geothermal Field, Costa Rica – Evidence of thermal evolution and a comparison of the mineralogy of an acid well and a neutral well. UNU-G.T.P., Iceland, report 6, 115-142.

Nietzen, F., 2012: Datos de masas extraídas y reinyectadas en el Campo Geotérmico Miravalles 1994-2012. Informe interno, C.S.R.G., I.C.E.

Taylor, W., 2011: Informe de la sismicidad durante el año 2011 en Miravalles. Informe interno OSIVAM, CSES, ICE.