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Precision Gravity Data of the Miravalles Geothermal Field an Ongoing Assessment

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ABSTRACT

For Miravalles geothermal field the geophysical data are abundant. For adding value to the decisions, precision gravity has been obtained since 1985. But it was not but until 1999 that measuring protocol with regular samplings systematically achieve an SD of 0.02 and 0.035 microgal. The strategy implied the simultaneous use of 4 gravimeters a digital one and 3 analogical, and the stations redistribution guided by the conceptual and reservoir model as main criteria. In the last campaign (2006) a correlation with the enthalpy measured in deep wells under exploitation at the north and injection trends towards the south was shown. The latter, and trends from individual stations, will be verified with a digital gravimeter in the next April of 2010. The purpose of the paper is to confirm a correlation between the steady production decline observed for the northern wells, the expansion of the steam cap, and the microgravity data. A modeling base on well temperature logs, and production head monitoring were also attempted. We are aiming to consider precision gravity as a tool that helps to evaluate the sustainability of the resource.

1. INTRODUCTION

Miravalles geothermal field is located about 200 km northeast of San José (Figure 1). It is associated with Miravalles volcano, a young andesitic stratovolcano, likewise associated to a caldera structure of more than 11 km in diameter. Gravity benchmarks were initially set at Miravalles in 1985. However the first condensing unit started in March 1994 and to date there are four generating units reaching a peak production of 155 MWe.

2. GEOLOGY AND GEOCHEMISTRY

Miravalles volcano resulted from activity developed since the Miocene from effusive to explosive deposits, which along with different structural activity has contributed in the formation of the Miravalles Geothermal Field.

It is considered that the heat source is related to the volcanic activity of the Miravalles volcano, and locally the depth to the 220°C isotherm and the alteration mineralogy in the northern sector supports this model. Likewise the fluid discharge can be traced following a north to south trend (Eduardo, 2005).

The reservoir is characterized as a liquid dominated mixture of two phase of 230-250°C at 700 meters deep with a thickness that varies from 0.8 to 1 km. The dominants fluids are sodium chloride with TDS of 5300 ppm, neutral pH and silica in about 430 ppm. Additionally acid aquifers are present, as well as a bicarbonate source to the west and southwest respectively.

It is assumed a 48 km^2 area of proven capacity well constrain by conductance values from magnetoteluric surveys. The predominant permeability very likely is by fractures according to the characterization of the wells.

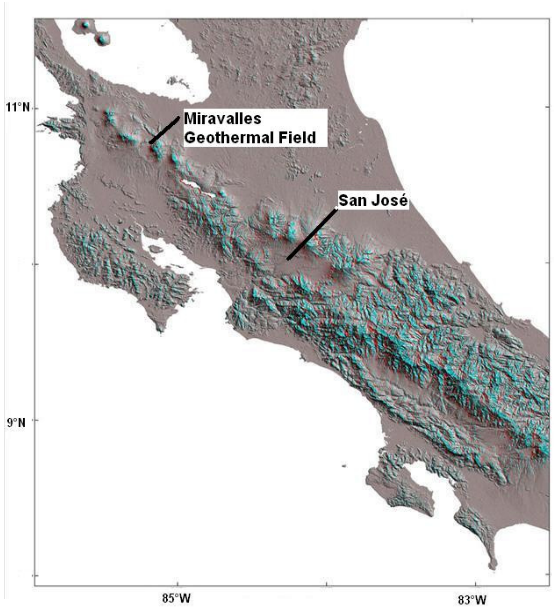

Figure 1: Location map of Miravalles Geothermal Field.

Geology, geochemistry together with the measured temperatures are showing an up flow zone toward the north and the distribution of three different fluids zones as was established previously.

3. METHODOLOGY

Between March 2003 and April 2006 four precision gravity campaigns were done over 26 benchmarks, which have been reoccupied at least once a year since 1999. In total 1174 measurements have been taken for the analysis.

In 1999 the survey was redesign, guided by the conceptual and reservoir model. Considering the temperature and enthalpy distribution, the sampling was decreased but its precision increased. Before 1999 the gravity measurements were being obtained through non regular campaigns with relative errors of more than 50 microgal.

The surveys covered an area of approximately 36 km^2, centered over the production area.

Since the beginning 3 gravimeters G model from LaCoste and Romberg were used simultaneously, and for 2003 a CG3 from Scintrex was also included. But for the last campaign the availability of the meters fail such that only two analog meters were in working conditions.

To ensure consistency between surveys the same gravimeters were used, at the end or beginning of the rainfall season to minimize the effect of any not confined shallow groundwater and or winds of the season.

Two profiles with measurements over the area of mayor gravity changes were added (approximately NS and EW) to evaluate the sensitivity of the data reduction, given the fact that the measurements can be carried out more times.

Reduction of the gravity and leveling data were done using the loop misclosure corrections and least squares network adjustments.

The measurement was edited for mistakes, blunders and tares and or drift rates, and its residuals were iteratively reduced. After the systematic errors were first treated, then care was taken establishing the sampling in a network style linking a station to other three such that precision is almost the same for each station. The gravity measurements were reduced to gravity differences, then the network was adjusted by minimum squares methods in a classical approach.

Gravity changes associated with the campaigns were obtained by preparing contour maps of the measured changes between 1999 and the survey being sample, in our case the last campaign was in 2006. In performing the subtraction it has been assumed that the gravitational effect of any change in the level of shallow cold ground waters that extended over the field is negligible. The shallow aquifers developed mainly in debris and lahar deposits, which mostly have very short residence time.

In Miravalles a basic conceptual model includes the characterization of acid and tight zones and targeting step-out drilling for production and injection.

Longman earth tide effect has been subtracted from the data trough the reduction process.

4. MICROGRAVITY CHANGES

Trough the improvement of the network, and the repeated measurements and standard error of +/- 12 micrgals relative to the base (Gra-124) was obtained. An accumulated microgravity anomaly was obtained using the year of 1999 as reference, when the network turns into a more robust design, however only the campaigns of 2003 and 2006 are reported.

It is trough the longer recording periods that it is realized the added value of knowing the evolution of the steam zone. In our case major changes occurs in the years 2000 and 2003.

The subsidence though existent, it is contributing in the equivalence of cumulative 3 cm. All gravity changes are assumed to be corrected for elevation changes and therefore only reflect mass changes at depth.

The first image (Figure 2) is showing circular forms, from the production and injection areas. Most of the production wells are in or close to the transitions among these two. The injection wells were 22, 24, 04 for the W, 28, 35, 59 for SE and 16, 26, 27, 56, 51 for the S, 04 is a well for mainly the disposal of cool down waters after the cooling towers and surface maneuvers.

The gravity values obtained had mean standard errors of 10-16 microgal for the years 2000 and 2003.

The most remarkable feature is the two pole character of the map showing the injection (with a dome shape in blue) and the mass extraction in green, yellow and orange to the NE and N. However in the transition between poles the differences are not solvable considering the error.

It is clear an injection pole to the SE, SW, (wells 22, 24, 04, and 28). A gradient is also seen with a NE-E trend following wells 42, 22, 23, on these days well 22 was been use as an injector.

Away from the central area to the NW the signal to noise ratio is smaller considering that the geothermal effect is lesser or not present, instead the shallow aquifers may be an active process.

To the E of wells 02, 19, 21 there is a superficial blocky lava flow that develops short term springs during the rainy season.

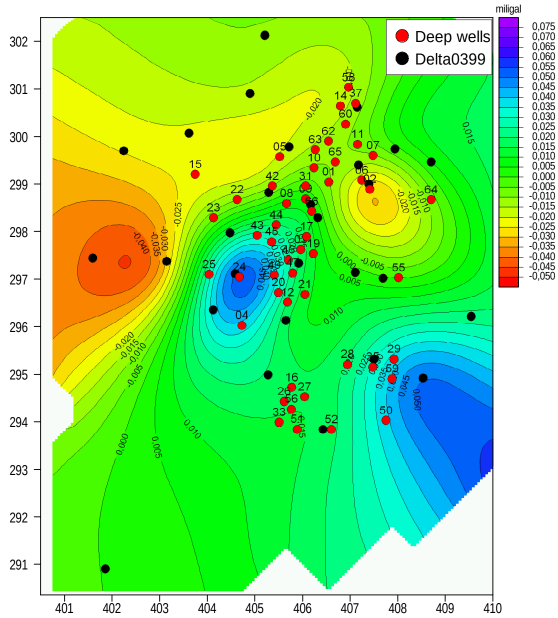

Figure 2: Gravity differences between 1999 and 2003. Measured stations are black dots.

Some quantitative profiles were calculated, the gravity effect of the models went through deciding a value for density change. The shape of the model was adjusted and its effects recalculated until the calculated and measured values were in good agreement. The main uncertainties in the modeling were with the values adopted for porosity and saturation of the lower part of the steam zone.

The geothermal field in the west and central area has undergone a more gradual pressure decline decelerated in the mid of 2003 when the mass withdrawal decreases after: the reduction of extraction, the increased injection in the south, its correspondence diminished injection in the west and the developing of the steam cap.

The field started in March 1994, and in 2003 the third unit of backpressure turbine was commisionated.

In figure 3 two anomalies persist, in yellow and blue, the production area close to well number 2 (enveloping contour of -0.02 mgal) showing this time a larger area, which might include well 5. Again the injection area related to well 04 is clear and most of the wells are distributed in the transition areas between the two poles.

The gravity values obtained had mean standard errors of 20-38 microgals for the year 2006.

It is suggested that where the signal seems lower or close to the error the solution of the anomalies is poor, therefore the trend or association has flat and smooth anomalies.

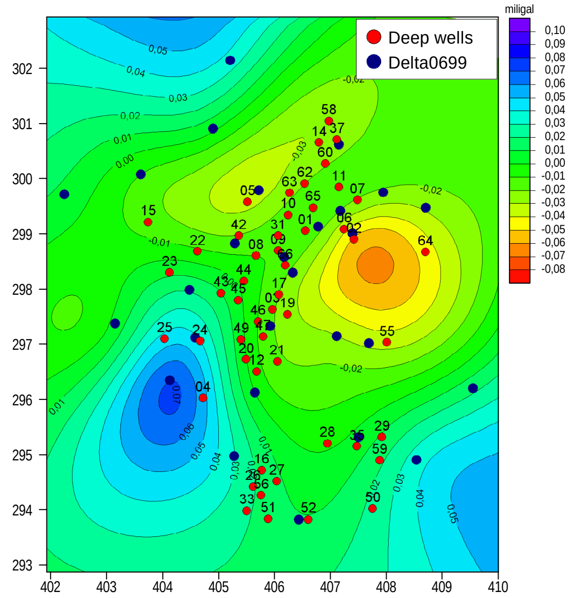

Figure 3: Gravity differences between 1999 and 2006. Stations measured are in black.

Again two gradient axis trending toward the NE-E, NE-SW in relation to the poles appears. But a trend NW-SE is becoming more important suggesting the relevance of the injection. After an early period of decreasing gravity over most of the field the gravity trends over the eastern and western steam zones have been very different since 1994.

It was considered that initially a liquid dominated two phase zone over a deeper liquid zone exist, that once the production started, soon caused the two phase zone to expand, and steam to formed.

After the initial stage of relatively easy heat extraction associated with production a pressure drawdown occur, in fact many fields have entered a phase of heat "mining" due to water flow through the reservoir whether it be liquid or vapor dominated as the rate of gravity change diminishes, suggesting that annual surveys may not resolve significant gravity differences.

As some of the major trends can be correlated to the start in operation of a third power plant, the maps of the same epoch are shown. Furthermore Miravalles field pressure decline showed a close correlation to the power plants shutdown, in Castro (2010) it was established that a 30% change of mass extraction or injection causes a change of 1 bar in one month.

Since the year 2000 the wells increase their steam production which caused very likely a reduction in the pressure drawdown (Castro, 2010) while the same mass production was almost kept constant. It should also be taken into account the injection policy in the southern wells area.

The highest pressure decline is located in the central area close to wells 45, 19, 37. The same behavior at the south with wells 59 and 27 occur.

5. A N-S PROFILE MODEL

According to the accumulated deformation measured by the precise leveling it results in 3 cm, which corresponds to a magnitude of *3 microgal per cm.*

Major changes are observed trending N-S. Therefore two profiles were recommended by Cummings (2001) as a way of lowering down the errors, because they can be easily located where the steam cap effects should be stronger. Here is shown only a NS profiles in Figure 4.

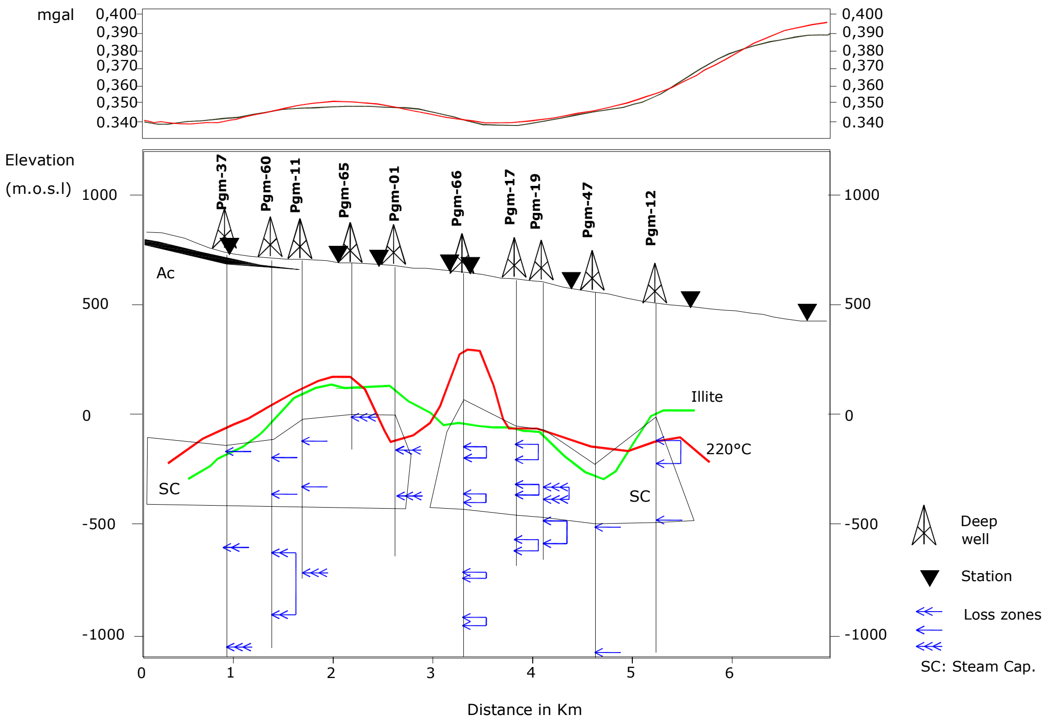

Figure 4: NS profile showing the extension of the steam cap (SC) in relation to Illite presence in a 100%, the isotherm of 220°C and feed zones (relatively categorized).

The profile shows the Illite content of 100%, and the temperature contour of 220°C. In Miravalles field the Illite is well correlated to the temperature, as an indicator of where the reservoir begins.

Using values detailed in Cummings 2001, it was modeled considering a 10% of porosity, an increment of the steam volume of 3% which correlates to a density decrease of 0.002 g/cm^3.

The temperatures logs suggested that the steam cap as it is caused by the boiling into the formation started at an elevation of -400 meters upward limited by the base of the clay cap where the Illite reaches 100%.

A shallow aquifer had to be infer, with greater density changes (3%). For a better adjust, it was necessary to consider two bodies instead of one.

The wells 65 and 01 produce totally from the steam cap zone, boiling from the formation.

6. CONCLUSIONS

In general the reservoir has responded rather quickly to reconfigurations of the well connections, reinjected fluids have been seen to return to the productions wells as evidenced by the augment of chloride content of the extracted fluids. Reservoir pressures have declined throughout the field, including the southern reinjection area. The increase in rate of pressure decline with the start up of Unit III was notable.

The amplitude and longitude of the anomalies are considered to be associated with a clear geothermal process, the signal/noise analysis point out a trend, making us believe that we have reach a threshold determined by the magnitude of the signal.

There are however signs that show the lack of resolution, such as the well 45 and 8 which have developed enthalpy changes expressed as an increase in non condensable gases and a pressure drawdown. Meanwhile well 12 have also shown a pressure decline but with almost no enthalpy change.

Gravity monitoring at the Miravalles geothermal field for the past 9 years showed a continuous decrease greater than 40 ugals near the center of the production area as a result of resource depletion. The negative gravity anomalies are primarily due to density/phase changes related to saturation changes in the rock in the shallow portion of the reservoir.

Subsidence delineated by precision leveling surveys is showing a minimum influence, with no adverse impact to the environment.

Precision gravity data could play an important role in refining an updating of the reservoir simulation.

The model suggest that wells increase in enthalpy as the wells dry out, but that may vary from wells that changes its enthalpy by cooling. The first ones may improve the steam cap appearance.

A gravity decreased is usually associated with a steam saturation increase.

It was possible to achieve adjusted gravity values of $\pm$ 12 microgal relative to the local base. Toward de periphery shallow waters have more influence, and the reservoir has less effect therefore non manageable noise is stronger.

Sometimes as in the loops form the SE and NW in the borders of the field the standard deviations were close to the mean but for the other loops the influence of the exploitation dynamics with ample differences became clearer.

Time series of stations from the centre of the field follow a trend correlation. But it is necessary to clean and enhance the signal trough a better water level and leveling controls.

It is foreseen after having more control observations of water tables from shallow aquifers, quantitative estimates by means of Bouguer slab.

We are expecting to implement the use of a digital Burris meter for improving radically the signal /noise ratio.

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