Mariposa Geothermal System: A Large Geothermal Resource in Central Chile (320MWe inferred)

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Abstract. The Mariposa Geothermal System (MGS) is located 300 km south of Santiago, Chile, included in the Tatara-San Pedro- Pellado volcanic complex and the western side of the Maule volcanic complex. The field is outlined by a 27 km^2 low resistivity MT anomaly with two lobes probably related to a clay cap associated with two principal upflow areas. The resource depth varies from 700 m to over 1000 m, depending on terrain. The inferred resource is 320 MWe. The reservoir is likely contained within the volcanic rocks of the Campanario (Miocene-Pliocene) and Curamallin (Eocene to Miocene) formations. Structural analysis suggests control by east-northeast vertical structures with perpendicular extension, that intersect regional important NS lineaments. Geothermal manifestations (steaming ground and fumaroles) occur at four locations surrounding the MT anomaly, where the steep terrain cuts the margins of the clay cap. Gas geochemistry from these sources indicates a liquid-dominated reservoir with benign characteristics, and temperatures of 200 - 290°C. Drilling the MGS has proven to be challenging and of the three slim holes drilled to date, none have penetrated into the reservoir. Two wells measured temperatures over 200°C in the shallowest part of the reservoir.

Keywords: Central Chile, geothermal system, slim hole, temperature-pressure well data, magnetotelluric survey, clay-cap.

1 Introduction

The Chilean Andes are the result of the subduction of the oceanic Nazca Plate beneath the South American Plate, at the Chile (or Atacama) Trench at a rapid rate of about 80 mm/year with a N78º convergence angle (De Mets, et al. 1994; Tamaki, 1999). This subduction is responsible for the volcanic activity within the Andes, and the production of numerous potential magmatic heat sources for geothermal fields.

The Mariposa Geothermal system discovered by Magma Energy Chile Ltda., is located in the Andes of the Maule region, included in the Tatara-San Pedro-Pellado Volcanic Complex (e.g. Dungan *et al*, 2001; Singer *et al*., 1997) and the western portion of the Laguna del Maule volcanic field (Hildreth *et al*., 2010). Both complexes have recorded intense volcanic activity during the Quaternary.

2 Magnetotelluric (MT) Survey

The MGS was discovered in 2009, after a MT survey carried out inside the Laguna del Maule and Pellado geothermal concessions. The field data acquisition, data processing and 3D inversion modelling of the results was conducted by Schlumberger (Geosystem). The study continued during 2010, completing a total of 92 stations.

The MT data identified a large (27 km^2) low resistivity anomaly area across the geothermal concessions. The four thermal areas that have been identified (Pellado, La Plata, Los Hoyos and Estero del Valle; Figure 1) all occur at the edges of this conductive feature. The anomaly defines a strong horizontal conductive layer that extends from south of the Los Hoyos thermal area to near the Pellado fumaroles. This conductive layer lies at about 500 m depth beneath most of this area and is overlain by a zone of high resistivity indicative of cool and unaltered volcanic rocks. The extent of the conductive layer is assumed to be indicative of the extent of the subsurface geothermal system.

The low resistivity layer is of the order of 300-400 m thick, and is overlain by very high resistivity material which corresponds to the unaltered Quaternary volcanics at the surface. The elevation of the base of the low resistivity layer varies between about 1700 and 2200 masl, and hence between about 250 m (near La Plata fumarole) and 1100 m below the surface (in the western lobe, approximately 3 km NNE of Pellado fumarole). It approximately coincides with the elevation of the smectite-rich zones that were observed in the three slimholes that have been drilled into the anomaly (next section). This conductor is typical of the clay alteration cap which forms over active geothermal systems. The shape of this feature highlights two main low resistivity centres joined by a narrow neck. It is possible that these may be caused by the presence of two upflow zones, which may or may not, be hydrologically linked.

3 Well Data

Three slim holes (core) have been drilled inside the MT anomaly. The holes (MP-01, MP-02 and MP-03) passed through thick Quaternary volcanic cover (high resistivity) reached a clay-rich layer (interpreted as a clay-cap). The

hole transacted the clay cap (based on MT, methylene blue and XRD analysis) and reached the top of the reservoir.

Temperature-pressure logs were conducted in the three wells using a KUSTER K10 instrument; during drilling and afterwards. The clay cap interpretation was reinforced by temperature measurements from the three slim-holes, indicating that the conductive cap corresponds to a zone in which temperatures increase with depth from about 50 or 100°C at the top of the conductor to about 200°C at its base, though admittedly the three slim-holes cover only a small part of the area of the resistivity anomaly (Figure 2).

4 Gas Geochemistry

Geothermal manifestations at the MGS occur in the borders of the MT anomaly. Gas geochemistry and XRD survey, have been carried on annually since 2009 up to 2012, at the four geothermal manifestations (Pellado, La Plata, Los Hoyos and Estero del Valle) included in the concessions Laguna del Maule and Pellado.

The existence of fumaroles is evidence of a high enthalpy geothermal system at depth, due to the fact that such manifestations do not occur in association with low enthalpy reservoirs. The relative proportions of gases in the MGS fumarole samples are typical of neutral high temperature geothermal reservoirs, no indications of acidic fluids have been found.

Gas geothermometry indicators at MGS are positive, from a development perspective. The hydrogen-argon geothermometer (Giggenbach, et al. 1991) which usually presents good correlation with the measured temperatures compared to other geothermometers, gives temperatures of 247-292°C, close to those obtained by using D'Amore and Panichi (1980), in the range 230-296°C. On the H_2/Ar versus CO_2/Ar plot (Figure 3), used to assess phase conditions, the samples plot slightly above the liquid equilibrium line, suggesting a two-phase or liquid-dominated deep reservoir with temperatures in the range of 200-250°C. Isotopic compositions support a local recharge of the reservoir, as expected. (Magma Energy Corp - ENERCO, 2011).

5 Summary

The results of two MT campaigns in the project area, have confirmed an extended (27 km^2) low resistivity anomaly distributed between the Laguna del Maule and Pellado geothermal concessions.

Geothermal manifestations located around the border of the MT anomaly, have reported favourable gas chemistry data, consistent with the presence of a liquid–dominated reservoir at depth. Geothermometers applied to samples from different years report stable conditions and reservoir temperatures in the range 247-290 °C. There is no evidence of acidic conditions

Three wells have been drilled in the eastern sector of the MGS. Technical difficulties and drilling under the rigorous winter conditions of the Chilean Andes, have prevented the deeper zones of the reservoir to be reached. The wells have recorded bottom hole temperatures close to 200°C. The thermal regime in the three wells obtained by KUSTER logs indicate increasing temperatures with depth suggesting that the conductive behaviour continue down the holes, to higher temperatures.

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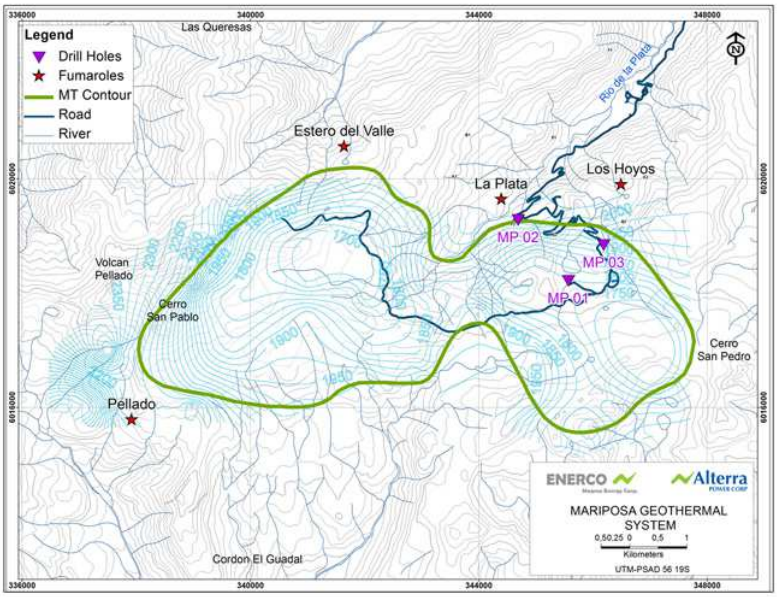

Figure 1. Combined 2009 and 2010 MT survey results. Low resistivity anomaly area is indicate by a green line. Location of thermal manifestations and slim-holes are shown.

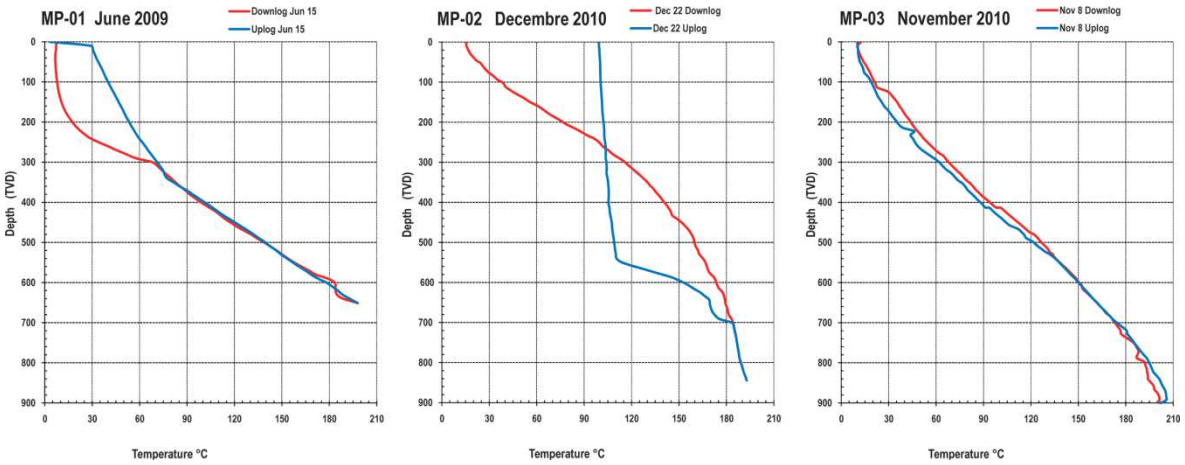

Figure 2. Temperature vs. depth logs for MP 01, MP 02 and MP 03 slimholes

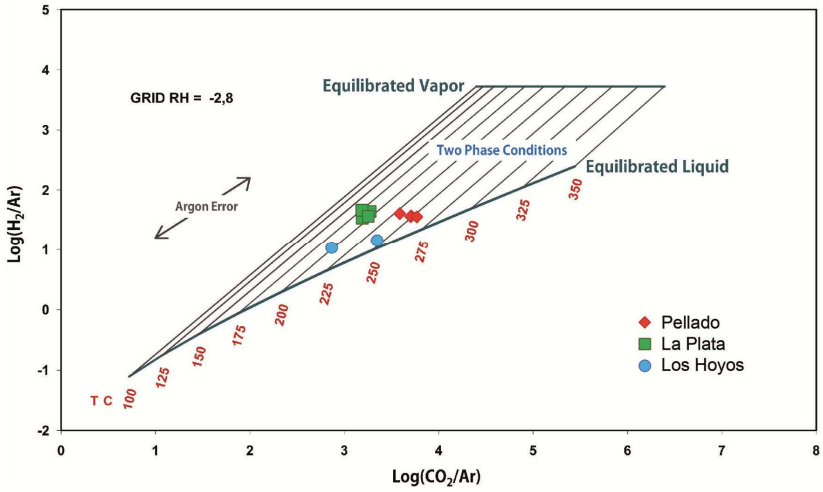

Figure 3. H_2/Ar-CO_2/Ar gas geothermometer showing gas samples from Pellado, La Plata and Los Hoyos fumaroles.