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Update on the Stable Isotope Geochemistry of the Leyte Geothermal Production Field

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ABSTRACT

Isotopic data monitoring from geothermal wells, springs, ground water and rainfall aims to update the stable isotope systematic of the Leyte Geothermal Production Field, Philippines. Isotope collection was conducted during the exploration stage and in 1990-2002 but was terminated due to the breakdown of the mass spectrophotometer isotope analyzer in 2002. With the procurement of a new isotope analyzer, sampling in Leyte resumed in 2010 and now becomes a routine geochemistry activity.

Isotope data, correlated with the geochemical characteristics of the fluids, elucidates the reservoir processes affecting the performance of the Leyte Geothermal Production Field including Tongonan-1 Sector which continues to produce for over 30 years. For example, production wells affected by incursion of injected brine show enrichment of stable isotope (from -1.19 to 0.22 $\delta^{18}O_{res}$‰) coinciding with reservoir chloride increase. Conversely, for some wells affected by dilute, cooler waters depict relatively depleted oxygen-18 isotope (at -1.6 to -1.70 ‰) which corresponded to lower chloride and gas levels. In areas where boiling is prevalent, there is an observed enrichment of stable isotopes, increasing total discharge CO_2 ($CO2_{TD}$) and discharge enthalpies greater than 2000 kJ/kg. Monitoring of isotopic trends and distribution in the area, together with geochemical trends, aids in mapping out the evolution of these reservoir processes. This also serves as a useful tool in evaluating the effectiveness of implemented strategies. As such, isotope geochemistry has been considered a valuable tool in managing the production field and in formulating resource strategies. Thus, isotope monitoring correlated with geochemical data must be continued to help us understand changes in field hydrology with continued mass extraction.

1. INTRODUCTION

Historically, isotope collection in Leyte Geothermal Production Field (LGPF) was conducted during the exploration stage and in 1990-2002 but was terminated due to the breakdown of the mass spectrophotometer isotope analyzer in 2002. Upon the procurement of a new isotope analyzer, sampling in Leyte resumed in 2010. Comparing the two instruments, each has its own benefits and drawbacks. In terms of accuracy and precision, they have comparable ranges such as shown below:

Criteria	Mass Spectrometer	Isotope Analyzer
Accuracy	$\pm\delta^2H$: $\leq$1.00 ‰ $\pm\delta^{18}O$: $\leq$0.10 ‰	$\pm\delta^2H$: 1.00 – 2.00 ‰ $\pm\delta^{18}O$: 0.25 - 0.50 ‰
Precision	$\pm\delta^2H$: $\leq$1.00 ‰ $\pm\delta^{18}O$: $\leq$0.10 ‰	$\pm\delta^2H$: 1.00 – 2.00 ‰ $\pm\delta^{18}O$: 0.25 - 0.50 ‰

Since the acquisition of the isotope analyzer, EDC has built up a good number of deuterium (δD or δ^2H) and oxygen-18 ($\delta^{18}O$) database. With these stable isotopes being part of routine sampling and monitoring, it is but appropriate to maximize their use in our operations. Figure 1 shows the correlation of some LGPF isotope data collected from different sources – thermal areas, surface waters and production wells. The black solid line is the Local Meteoric Water Line (LMWL) of the Greater Tongonan as established by Isidro and others in 1992. The black and blue dashed lines are the regression lines for Tongonan and Mahanagdong wells, respectively. Note that these lines intersect with the LMWL at the point where the surface waters plot suggesting that the fluids from the wells are mixture of andesitic waters ($\delta^{18}O$ of 10 ± 3‰ and δ^2H of -20 ± 10‰) and meteoric waters. These are sources of natural waters where andesitic is defined by Giggenbach as recycled sea water which has been subducted in regions with andesitic volcanism or convergent plate volcanism, while magmatic waters is defined as that equilibrated with magma regardless of its initial origin. Meteoric water, on the other hand, refers to water which has been recently involved in atmospheric circulation, including pluvial, vadose and other groundwaters (Cindrich and Gundmundssori, 1984).

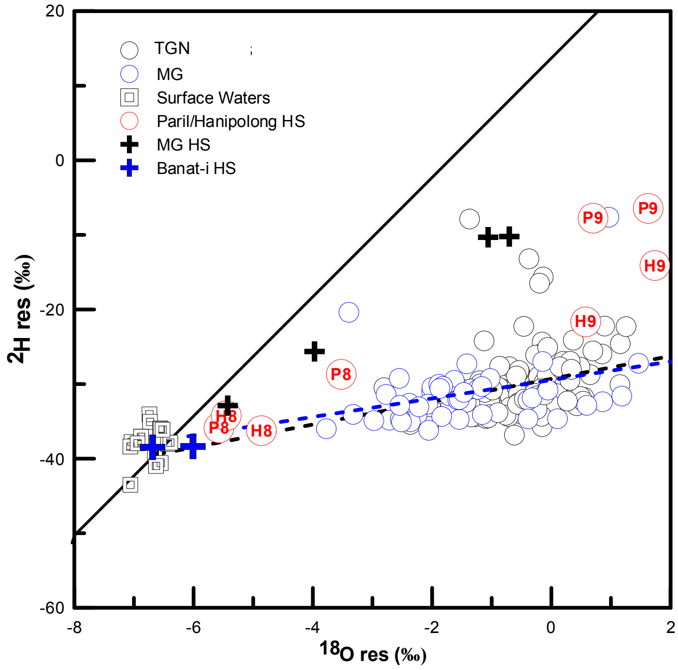

Figure 1. Crossplot of δ18Ores vs. δ2Hres of wells, springs and surface waters of LGPF

2. ISOTOPIC DATA AS A TOOL IN GEOTHERMAL RESOURCE MANAGEMENT

The benefits of using natural tracers such as δ^2H and δ^{18}O are - they are less expensive and are continuously available as tracer. Although the information they provide is mainly qualitative, these information is very useful more especially if interpreted in tandem with physical and chemical data. For example, isotope data evaluation to determine the effects of exploitation in Tongonan-1 from 1983 to 1995 was documented in 1996 (Salonga and Siega, 1996) The evaluation identified two major reservoir processes, mixing of re-injected waters and steam addition as a result of localized drawdown, as the effects of exploitation. The former process was evidenced by enrichment of heavy isotopes and reservoir chloride (Clres), with corresponding decline in temperature based on silica (TSiO2) and discharge enthalpy. Steam addition manifested from fluctuating stable isotope data at consistent TSiO2 but discharge enthalpy increased to above 1800kJ/kg. The results of the evaluation led to the recommendations of optimizing injection and ensuring the completeness of baseline stable isotope data during the pre-commissioning and discharge tests for use as inputs to future modeling works for the Tongonan reservoir (Salonga and Siega, 1996).

3. EVALUATION OF RESERVOIR PROCESSES WITH THE AID OF ISOTOPIC DATA

Isotopic data of which we mean either or both δD and δ^{18}O, correlated with the geochemistry of the fluids, elucidates the reservoir processes affecting the performance of LGPF. For more than 25 years of production, massive extraction resulted to influx of brine and condensate from injection sinks and cooler waters from the peripheral areas towards the production sectors. The discussion will focus on the use of stable isotopes as monitoring tool in determining sources of geothermal fluids and the physico-chemical processes affecting its composition.

For EDC, δD and δ^{18}O stable isotopes data have been used for the assessment of the following processes: mixing with cooler or more dilute waters such as mixing of in-situ geothermal water with either reinjected fluid returning to the production wells, peripheral waters, or other more dilute waters, or with steam condensates, or boiling process. For reservoir processes elucidation in this paper, isotopic data used are at reservoir condition. Here, as-analyzed isotopic data of separated water and steam condensate are first reduced to total discharge (TD) composition using sampling condition parameters. TD composition is then further converted to reservoir composition by using reservoir steam fraction and equilibrium fractionation factor between water and steam which are both based on TSiO2 (Salonga and Siega, 1996). For this paper, separate discussions will be made for the Tongonan and Mahanagdong Sectors. Figure 2 provides the common reservoir processes in these two sectors.

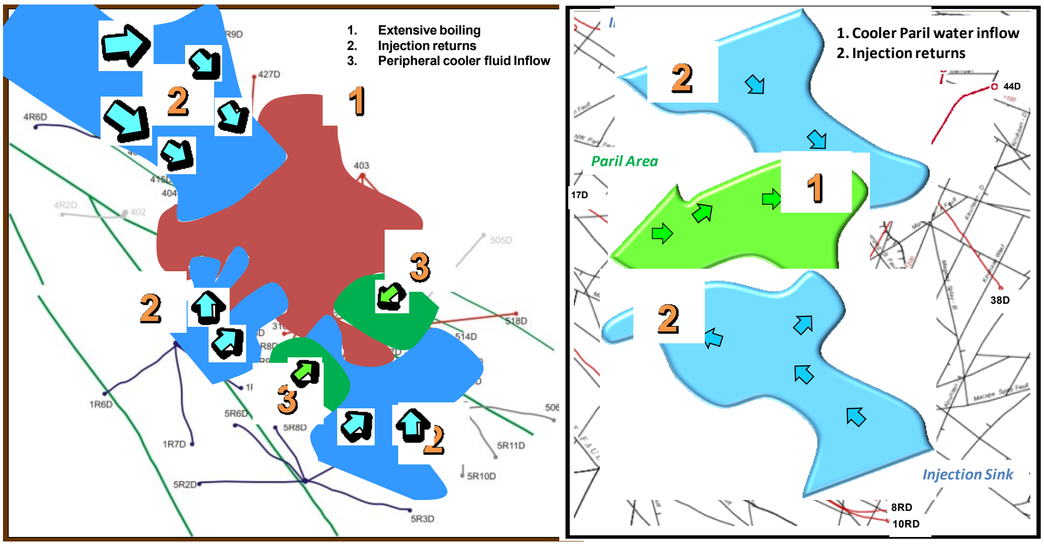

Figure 2. Tongonan map (left); Mahanagdong map (right)

3.1 Tongonan

Recent stable isotope data were compared with the data during the commercial operations of Tongonan in the 1990's. Boiling is evident in Tongonan wells which have discharge enthalpies greater than 2000 kJ/kg. There is an observed increasing $CO2_{TD}$ and enrichment of stable isotopes. In the Upper Mahiao sector, only a few numbers of historical data are available which limits the comparison of the isotopic data. Except for production wells in the northern area, flanking the injection sink and affected by brine and condensate returns, most Upper Mahiao wells have enthalpies greater than 1800 kJ/kg and isotopes ranging from -0.98 to 0.58 δ^{18}Ores‰ which had positive shifts due to boiling. Positive shifts of δ^{18}Ores‰ will even be more expected with the recent injection strategies implemented – moving farther from the production area the condensate and brine injection.

In South Sambaloran, well 301 is the only well with baseline data collected in August 1983 based on the baseline chemistry report in 1996 (Salonga, et al., 1996). However, latest reservoir oxygen-18 levels ranging from -1.10 to 0.43‰ are more enriched due to boiling similar in levels to Tongonan wells with discharge enthalpies exceeding 2000 kJ/kg. In contrast, some wells have relatively depleted oxygen-18 isotope at -1.6 to -1.70 ‰, dilute Cl and low gas levels due to incursion of cooler, dilute and degassed peripheral fluids.

The Malitbog sector located at the major outflow of the field,has diluted Clres (3,000 to 5,000 mg/kg) and depleted isotopic levels (-2.08 to -1.15 ‰ δ^{18}Ores). However, due to pressure drawdown in the area this has resulted to the incursion of brine from the injection sink to the Malitbog wells. Clres increased to as high as 10,000 mg/kg and enrichment of stable isotope is evident with values ranging from -1.19 to 0.22 δ^{18}Ores‰.

2.2 Mahanagdong

Mahanagdong, having a different hydrothermal system from that of Tongonan Geothermal Field, has a comprehensive isotope discussion by Dacillo and Salonga (2004). The northeastern part of the field was identified to be the center of the resource based on the geochemical and isotopic distribution. The area was identified to be the hottest having a temperature of 300°C and most isotopically enriched with δ^2H = -34.8‰ and δ^{18}O = -0.39‰, where the parent fluid is composed of 34% magmatic and 64% meteoric waters.

However, with the continuous mass extraction since the commissioning of the Mahanagdong Power Plant in 1997, incursion of cooler waters specifically Paril waters coming from the Paril area in the northwest was observed as early as 1999, brine from injection pad in the north and brine from injection pad in the south affected the geochemistry and performance of the production wells. These reservoir processes were evidenced by geochemical data and isotopic data and further confirmed by tracer tests conducted in 2003 (Herras, et al., 2005) and 2011.

Shown in Figure 3 is a crossplot of δ^{18}Ores versus Clres containing the 1997 baseline data and 2011 data for wells which are affected by brine returns from MGB3 (in red solid circles) and MGRD1 (in blue solid circles). MGB3 and MGRD1 brine are represented by black squares labeled B3 and R1. These brine returns are used to provide mass and pressure support. Using mass balance, MGB3 and MGRD1 brine are 49% and 57%, respectively, in the production wells affected by these returns. Figure 4**,** on the other hand, shows a crossplot of $CO2_{TD}$ and discharge enthalpy (H) that exhibits effects of brine returns and cooler water inflow to production wells, represented by open squares and circles, with years of exploitation. The evident effects are the reduced gas levels (<50mmo/100mol $CO2_{TD}$) in the discharge of production wells after incursion of degassed injected brine and groundwater, and liquid enthalpy as brine returns and groundwater are relatively cooler.

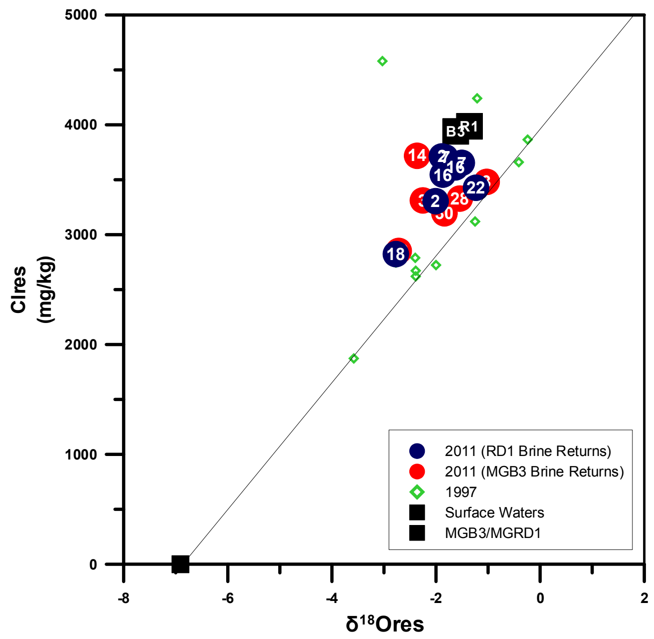

Figure 3. Clres and δ^{18}Ores data have affinity towards the injected brine levels.

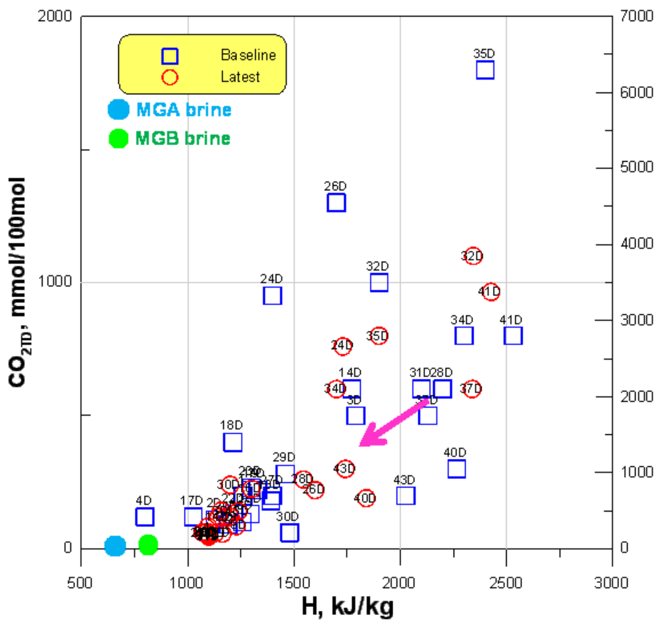

Figure 4. Crossplot of CO2 total discharge vs enthalpy (H) showing migration and affinity of discharge characteristics of wells towards injected brine (represented by blue- and green-filled circles), and well MG4D and MG17D which represents cooler Paril groundwater.

Figure 5 correlates Clres data with isotopic data. The data in 1997, 2001 and 2011 are represented by yellow, blue and red solid circles, respectively. Solid squares represent the mean values of δ^{18}Ores and Clres in 1997 (yellow), 2001 (blue) and 2011 (red) while hollow squares represent the surface waters of Mahanagdong. From a baseline of -2.1 ‰ in 1997, a negative shift to -2.3 ‰ of the mean δ^{18}Ores of the representative production wells of Mahanagdong in 2001 has been observed due to incursion of the isotopically-depleted Paril waters. In 2011, the mean isotopic level remained at -2.3 ‰ in 2011 indicating that overall the net influx of Paril waters has been arrested. The plots further illustrate that while we had initial dilution in Cl and depletion of δ^{18}Ores from 1997 to 2001 due to Paril cooler waters, the mean Clres and δ^{18}Ores have stabilized at 3000 mg/kg and -2.3 per mille δ^{18}Ores, respectively, from 2001 to 2011. This suggests that the optimized brine injection is working and appear to have regulated the influx of Paril waters. But, for further optimization, it would be more prudent to spread and shift the center of extraction farther away from central Mahanagdong to further regulate the influx of Paril waters.

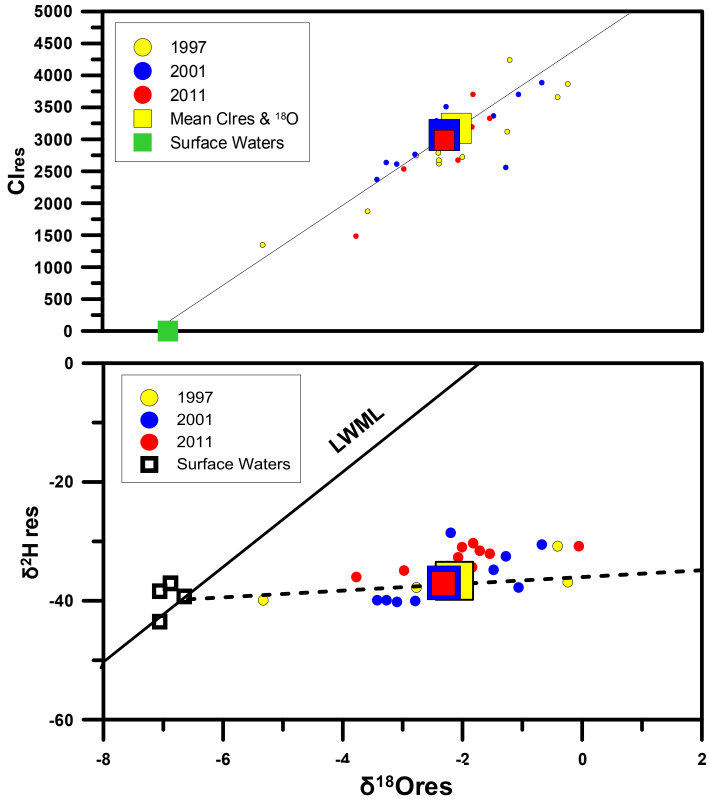

Figure 5. Correlation of isotopic and geochemical data since 1997 up to 2011.

SUMMARY AND CONCLUSIONS

Isotopic data, correlated with the geochemical characteristics of the fluids, elucidates the reservoir processes affecting the performance of the Leyte Geothermal Production Field including Tongonan-1 Sector which continues to produce for over 30 years. With the continued exploitation and mass extraction from the reservoir, changes were expected. The common response to both Tongonan and Mahanagdong fields was the incursion of cooler fluids, such as injected brine returns, to the drawndown production area. On the other hand, boiling is experienced in the central area of the production field particularly in Tongonan as exhibited by high discharge enthalpy of the affected wells. These reservoir processes have been confirmed by geochemical and isotopic data trends. Monitoring of stable isotopes (D and O-18) is an invaluable tool in managing a geothermal resource and formulating sustainability strategies. However, the isotope data is most beneficial if used with available geochemical, geologic and hydrologic data.

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