STABLE ISOTOPE SYSTEMATICS IN TONGONAN-1 PRODUCTION FIELD LEYTE AFTER 12 YEARS OF COMMERCIAL OPERATIONS

F.L. Siega and N.D. Salonga

PNOC-Energy Development Corp. (PNOC-EDC), Fort Bonifacio, Makati City, Philippines

ABSTRACT

The stable isotope data during the commercial operations of Tongonan-I production field from 1990 to 1995 are compared with their pre-exploitation levels and with the trends of well chemistry and discharge enthalpy. The changes on the stable isotope composition of the fluids from production wells and reinjection lines provided evidences on two reservoir processes, namely, mixing of reinjected waters with the reservoir fluids, and steam addition induced by localized drawdown of the deep liquid reservoir.

The entry of reinjectedfluids in the production sector of TIPF evinced on the enrichment of heavy isotopes and Cl_{res} *in the liquid-dominated wells of Mahiao and Sambaloran sectors. This process is also marked by the decline in* $T(SiO_2)$ *of the waters,* CO_{2td} *in vapour and well discharge enthalpy. The wells lying within 1.50 km radius from the TIPF reinjection sink, like wells 101, 213 and 214, are highly affected by the reinjectedfluid breakthrough. However, because of only about 1.00 to 1.50%* $\delta^{18}O$ *difference between the reservoirfluids and the reinjected waters, initial influx of reinjected waters into the production wells did not clearly evince on the changes of the stable isotopes.*

Steam addition is evident on the production wells proximate to the Upper Mahiao sector, such as wells 102, 106, 108 and 110. This process is manifested on the incoherent trends of $\delta^{18}O$ *and* δH. *The* $T(SiO_2)$ *of the fluids remain unchanged while the discharge enthalpy of the wells exceeds 1800 kJ/kg. Based on the patterns of* $\delta^{18}O$ *and* δ^2H, *stable isotopes will be useful as natural tracers of reinjection water breakthrough into the liquid-dominated reservoir of Malitbog and South Sambaloran sectors, as well as on the entry of cooler fluids from the north into the Upper Mahiao sector. However, stable isotopes may not be effective tracers of reinjected fluids in the wells of Upper Mahiao sector because of their high steam contents and the nearness of their isotopic composition with the reinjected waters.*

1.0 INTRODUCTION

The Tongonan geothermal field, situated in north-northwest Leyte (Fig. 1), consists of five sectors, namely the Mahiao, Sambaloran, South Sambaloran, Upper Mahiao and Malitbog sectors. The Mahiao and Sambaloran sectors belong to the Tongonan-1 Production Field (T1PF), the first field in Tongonan that was put into commercial operations since 1983. The Mahiao and Sambaloran sectors are composed of sixteen (16) production wells and six (6) reinjection wells. To date, only twelve (12) production wells are on-line to the 112.5-MWe power plant.

Isotopic investigations in Tongonan geothermal field started as early as 1974 which became extensive from 1978 to 1983. These include the works of Glover (1975), Barnett (1979), Camales (1980), Hulston et al. (1982), and Alvis-Isidro et al. (1993). The pre-exploitation data from these works are compiled and presented in this paper. Since 1990, water and vapour samples for stable isotope analysis have been collected from production wells and reinjection lines in TlPF. All isotope analysis were carried out in IAEA laboratory in Vienna, Austria. These data are analyzed in this report with the following objectives: (1) to assess the isotopic changes in well discharge fluids in T1PF; and (2) to identify the reservoir processes that have brought about the isotopic changes.

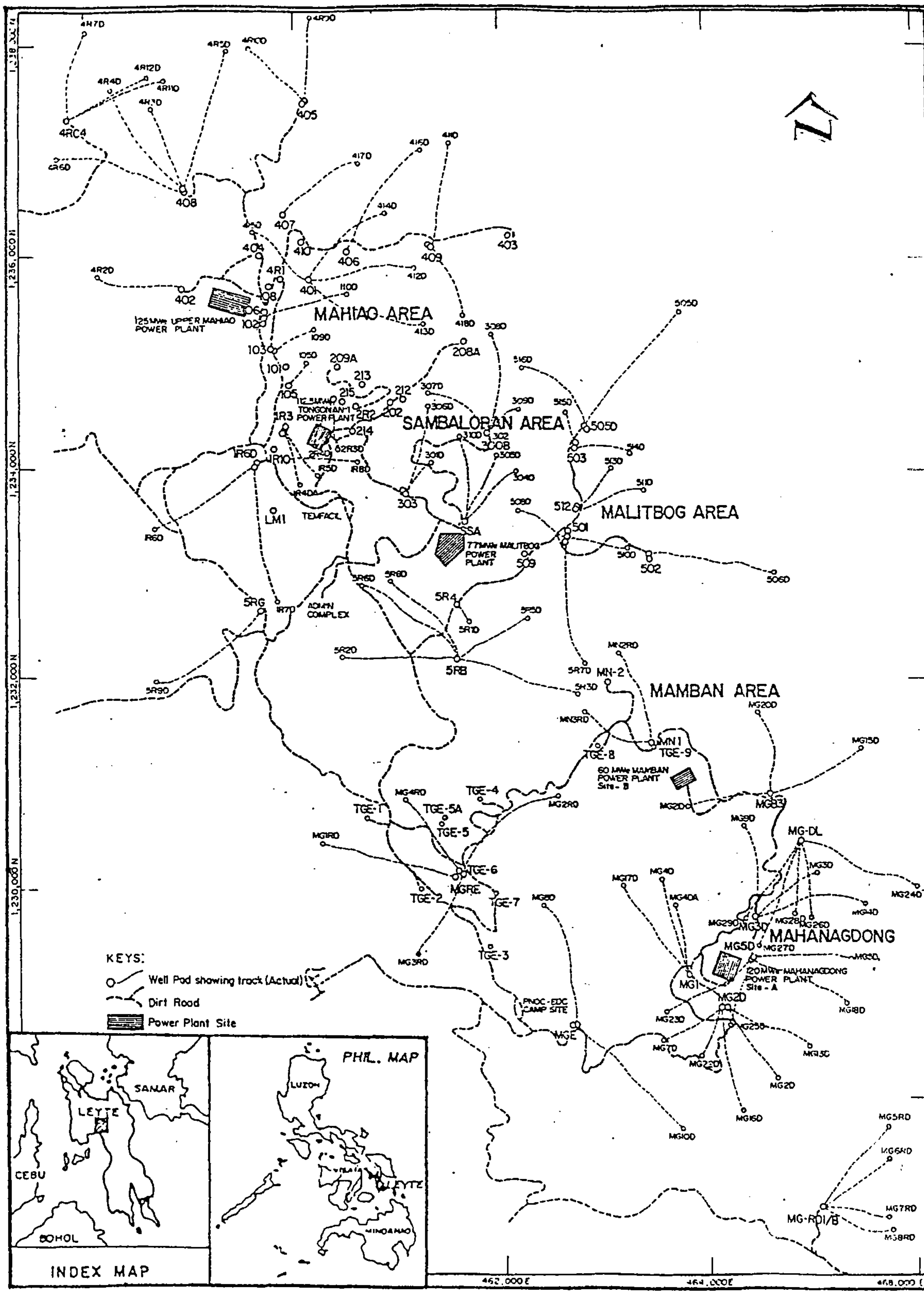


Figure 1. Location Map of Tongonan geothermal field showing the different sectors and well tracks.

2.0 PRE-EXPLOITATION ISOTOPIC COMPOSITION (1978-83)

The reduced isotopic data of well discharges, and selected stable isotopes data of downhole samples fiom 403, 105D and 202, are plotted with the Local Meteoric Water Line (LMWL) in Figure 2. As established in 1992 (Alvis-Isidro et al.), the LMWL in Tongonan has the following equation:

$$\delta^2H = (8.0 \pm 0.8)\delta^{18}O + (13.7 \pm 1.8) \qquad \textbf{Eqn. 1}$$

The distribution of data points fiom well discharge and downhole fluids generate the following regression line:

$$\delta^2H = 1.26*\delta^{18}O - 32.80 \qquad \textbf{Eqn. 2}$$

The intersection of the regression line with the local meteoric water line (LMWL) is defined by points $\delta^{18}O$ = -7.2‰ and δ^2H = -42.0% which could represent the isotopic composition of the meteoric recharge. The Tongonan wells show positive $\delta^{18}O$ shift of about 3.5-6.0‰ from the LMWL which is interpreted to be the results of mixing of andesitic waters ($\delta^{18}O$ = 10 ± 3‰, δ^2H = -20 ± 10‰) with the meteoric water recharge (Giggenbach, 1992). This mixing also results to positive shift in δ^2H.

The general distribution of stable isotope is reflected in the iso-$\delta^{18}O$ contour map across Tongonan field as of 1983 in Figure 3. Wells 407 and 410 in Upper Mahiao sector defined the area with the most isotopically enriched waters. The waters become isotopically depleted towards the Malitbog sector.

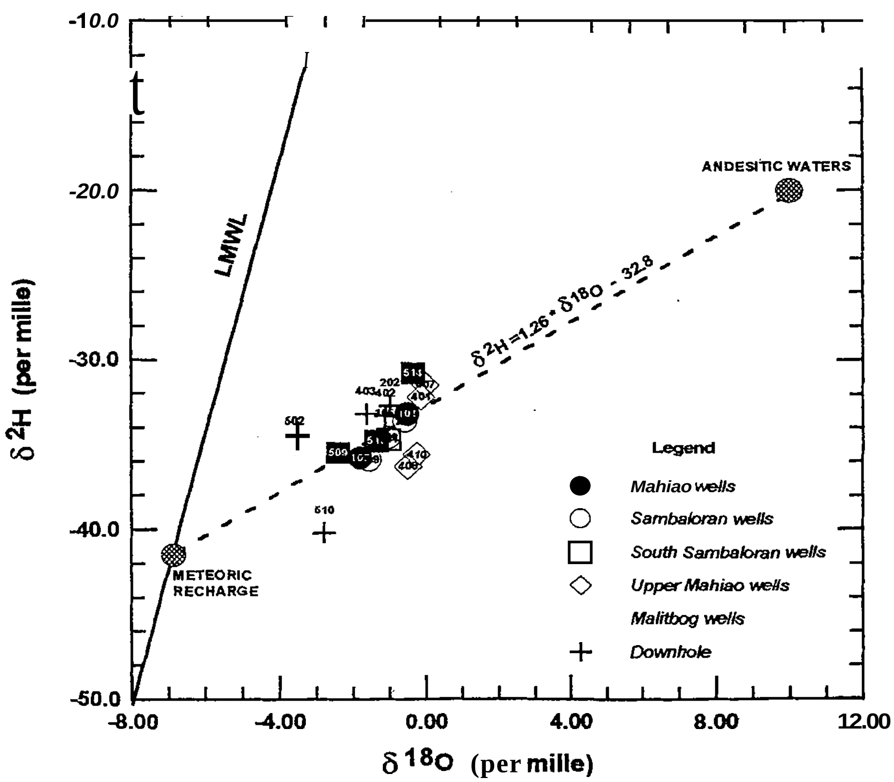


Figure 2. Baseline cross plot of $\delta^{18}O$ and δ^2H of the production wells in Tongonan geothermal field.

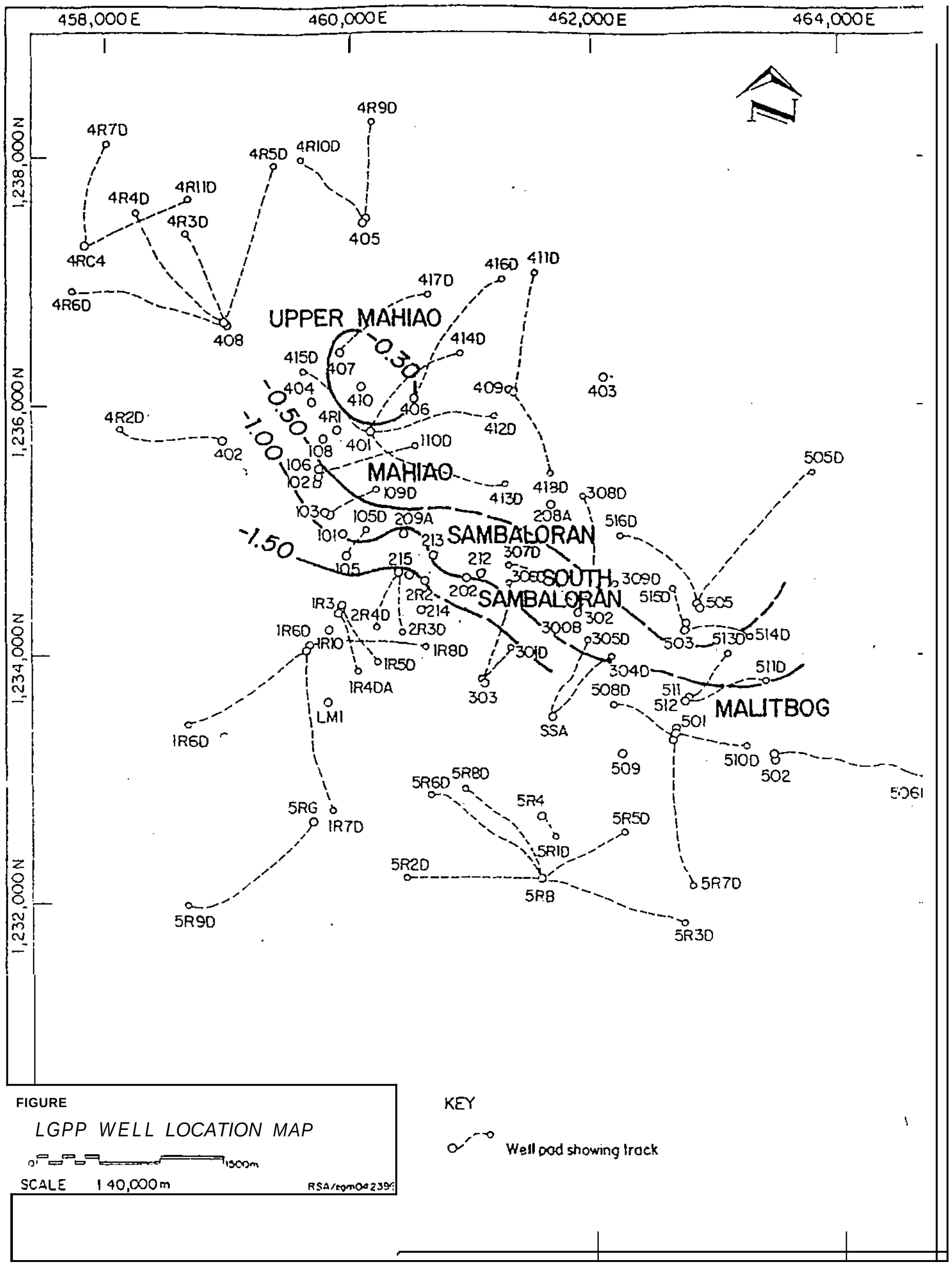


FIGURE
LGPP WELL LOCATION MAP

3.0 EFFECTS OF EXPLOITATION ON ISOTOPIC COMPOSITION

The production wells in Mahiao and Sambaloran sectors *can* be classified into three, namely, the liquiddominated wells, wells with two-phase **fluids,** and vapour-dominated wells. The liquiddominated wells **or** those with dscharge enthalpy **of** less than 1500 kJ/kg include wells 101, 105D, 202, 212, 213, 214 and 215. These wells lie within 1.0-1.5**km** radius **from** the reinjection **sink of** Tongonan-1 Production Field (Fig. 1).The wells with two-phase **fluids** or those with discharge enthalpy **of** about 1500-1800 kJ/kg include wells 103 and 209A. **These** wells lie about 1.0-1.5km north of the TlPF reinjection **sink.** Wells 102, 106, 108, 109D **and** 110D have discharge enthalpies **of** around 1800 kJ/kg and thus they are classified as vapour-dominated wells. **All of** the vapourdominated wells lie outside the 1.5 km radius north of the TlPF reinjection **sink** and near to the **Upper** Mahiao sector.

3.1 $\delta^{18}O$ vs. $\delta^{2}H$

The present $\delta^{18}O$-$\delta^{2}H$ cross plot **of** the production wells and reinjection lines in **TIPF** is shown in Figure **4** with the baseline regression line (Eqn. **2).** The reinjected fluids have composition **of** $\delta^{18}O$ = **0.24** to 0.78‰ and $\delta^{2}H$ = **-31.40** to **-24.00%** and **are** more isotopically enriched relative to the production wells and baseline data (Salonga and Siega, **1996).** The **data** points of the liquiddominated wells appears to be coincident with the baseline regression line, but relative to the available baseline data points, the wells become more enriched with heavy isotopes and have shifted towards the reinjected water **data points.** The vapourdominated wells, **lying** near to the Upper Mahiao sector, have incoherent **trends** in stable isotopes which possibly indicate ***steam*** addition induced **by** localized drawdown of the liquid reservoir. The **boiling** occurring during the upward movement of fluids at wellbore with temperature greater than **230°C** produces a residual liquid depleted in $\delta^{2}H$ but enriched in $\delta^{18}O$, and a ***steam*** phase enriched in $\delta^{2}H$ but depleted in $\delta^{18}O$. **The** effect of this process is more pronounced in $\delta^{2}H$ rather than in $\delta^{18}O$ composition of the fluids coming from the vapourdominated wells. **As** in the case **of 102** and **106 (Fig.** 5), the incoherent trends in the isotopic composition **of** the fluids with time **is** postulated to be the result of localized drawdown of the liquid reservoir and the degree of change depends on the quantity **of *steam*** produced and the extent of fractionation between ***steam*** and water at temperature of separation

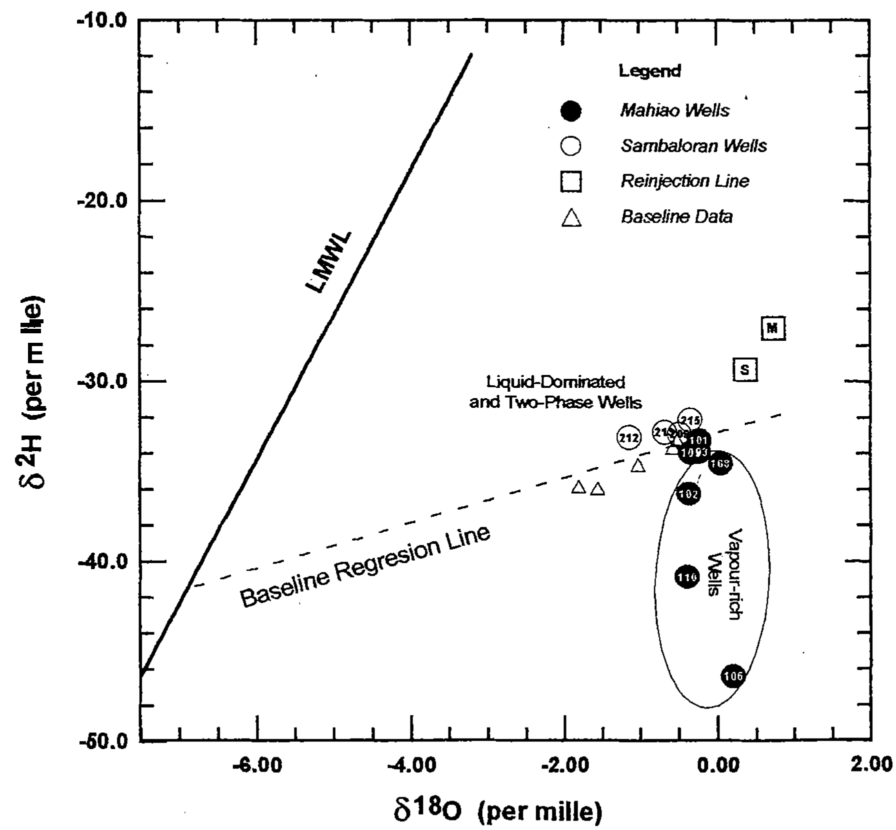


Figure 4. Cross plot of $\delta^{18}O$ and $\delta^{2}H$ in TIPF as of 1995. S stands for Sambaloran RI; M stands for Mahiao RI.

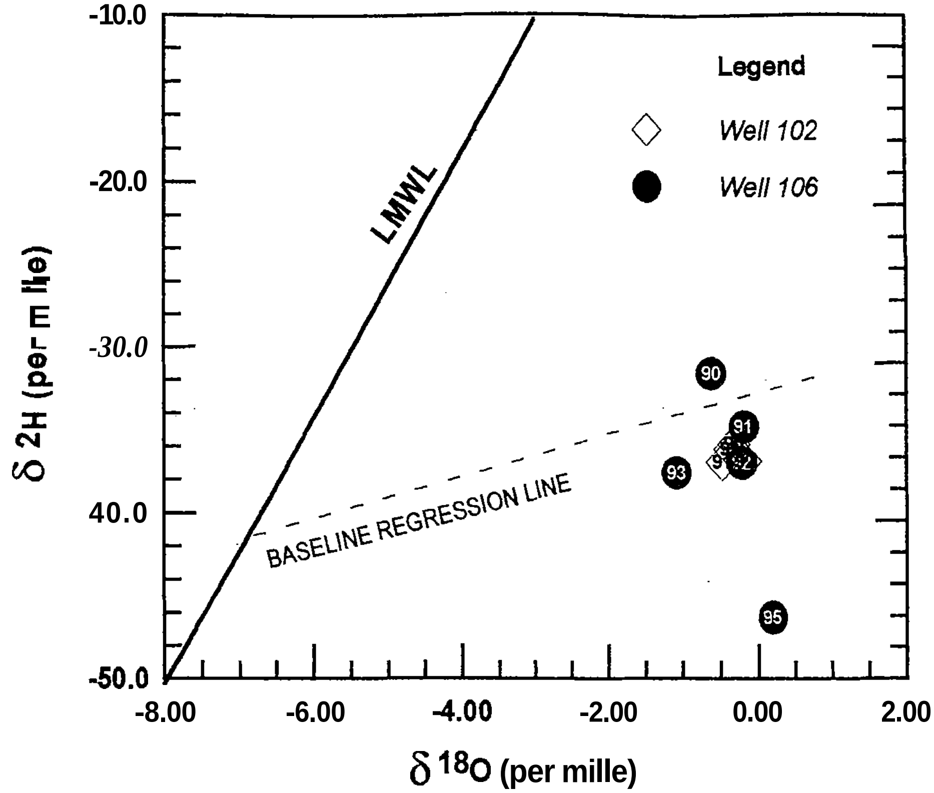


Figure 5. Cross plot of $\delta^{18}O$ and $\delta^{2}H$ of wells 102 and 106 with time

3.2 $\delta^{18}O$ vs. Cl_{res}, $T(SiO_2)$, CO_{2td}

The cross plots of $\delta^{18}O$-$T(SiO_2)$ and $\delta^{18}O$-CO_{2td} in Figures 6 and 7, respectively, show that the present data points of the liquiddominated wells generally plotted below the baseline regression line and along the RI fluid mixing line. In the cross plot of $\delta^{18}O$-Cl_{res} (Fig. 8), the same data pints plotted above the baseline regression line and appear to have shifted towards the reinjected water data points. These trends in the cross plots illustrate the changes brought about by the entry of reinjected waters, with estimated temperature of 160°C and Cl of 13500-14500 ppm, to the production wells near to the TlPF reinjection sink. The present reservoir fluids have become cooler, less gassy, more mineralized and more enriched with heavy isotopes. On the other hand, the trend of the vapurdominated wells in the cross plots (Fig. 6-8) suggests that there are already chemical manifestations of the reinjection fluid breakthrough in the area of wells 102, 106 and 110. The data points of these wells appear to be shifting towards the wells affected by RI breakthrough. This trend affirms with the earlier studies on chemical and physical changes in wells 102, 106 and 108 which have identified influx of reinjection fluids into wells 102 and 106 since 1992 on the basis of declining trend in discharge enthalpy and increasing trend in Cl contents of the fluids (Salonga et al., 1996). However, this is still not clearly reflected in the changes of stable isotopes possibly due to the nearness of their isotopic composition with the reinjection waters.

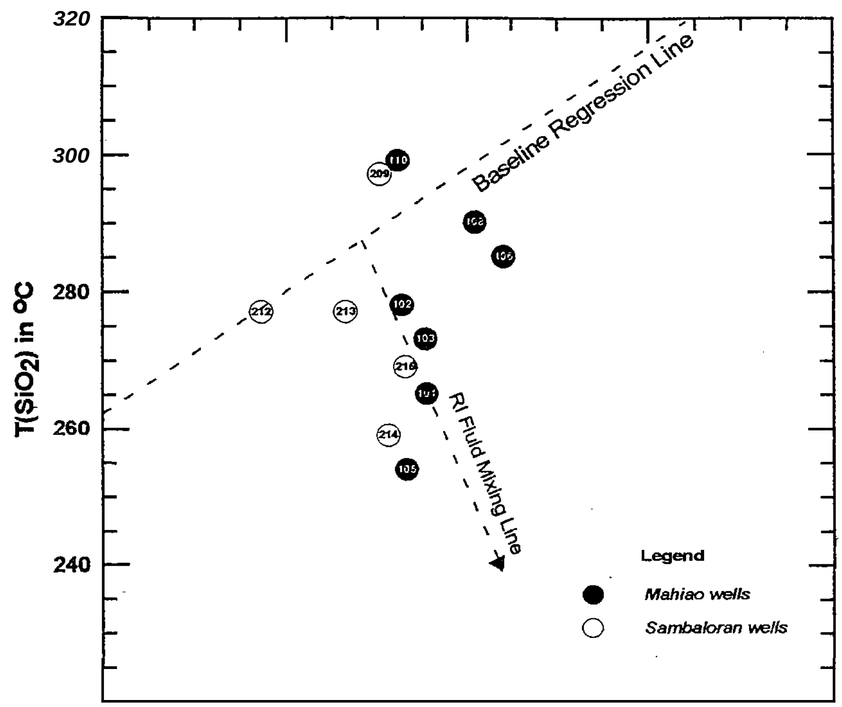


Figure 6. Cross plot of $\delta^{18}O$ and $T(SiO_2)$ in TIPF as of 1995.

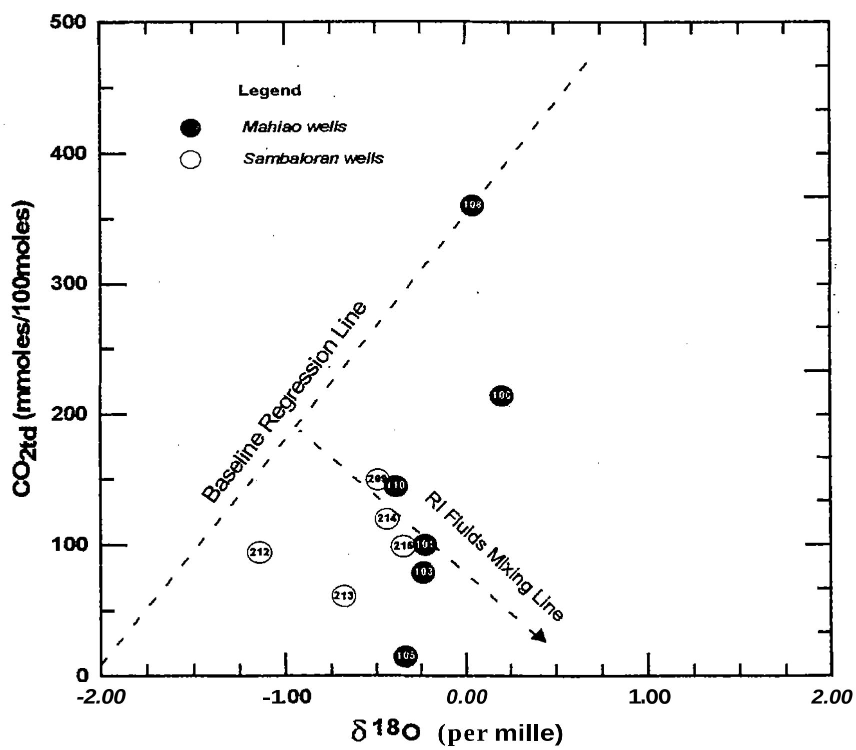


Figure 7. Cross plot of $\delta^{18}O$ and CO_{2td} in TIPF as of 1995.

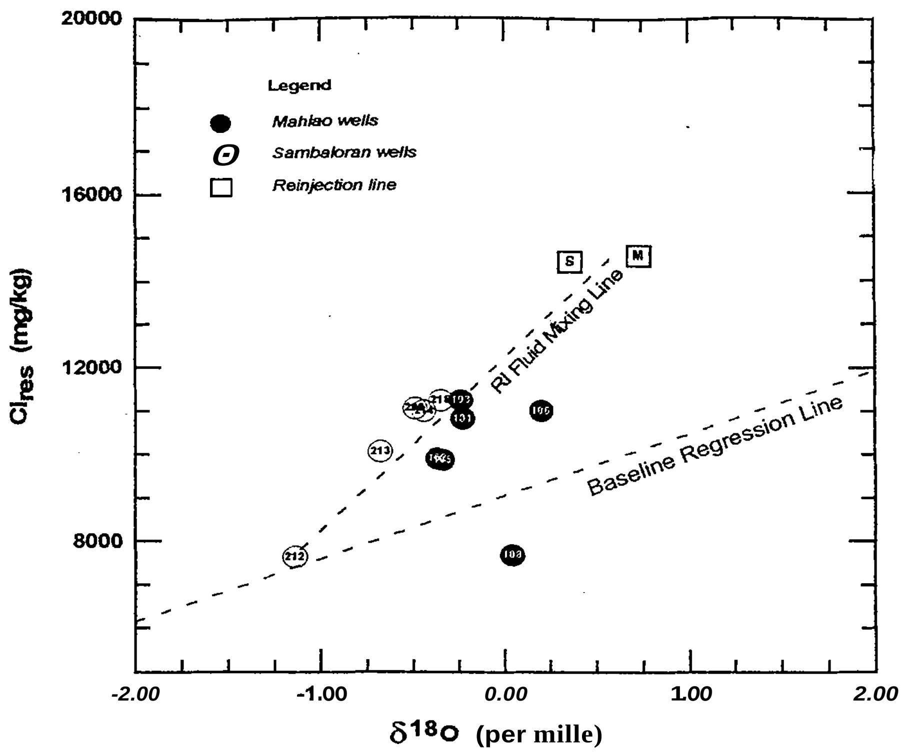


Figure 8. Cross plot of $\delta^{18}O$ and Cl_{res} in TlPF as of 1995. S stands for Sambaloran RI; M stands for Mahiao RI.

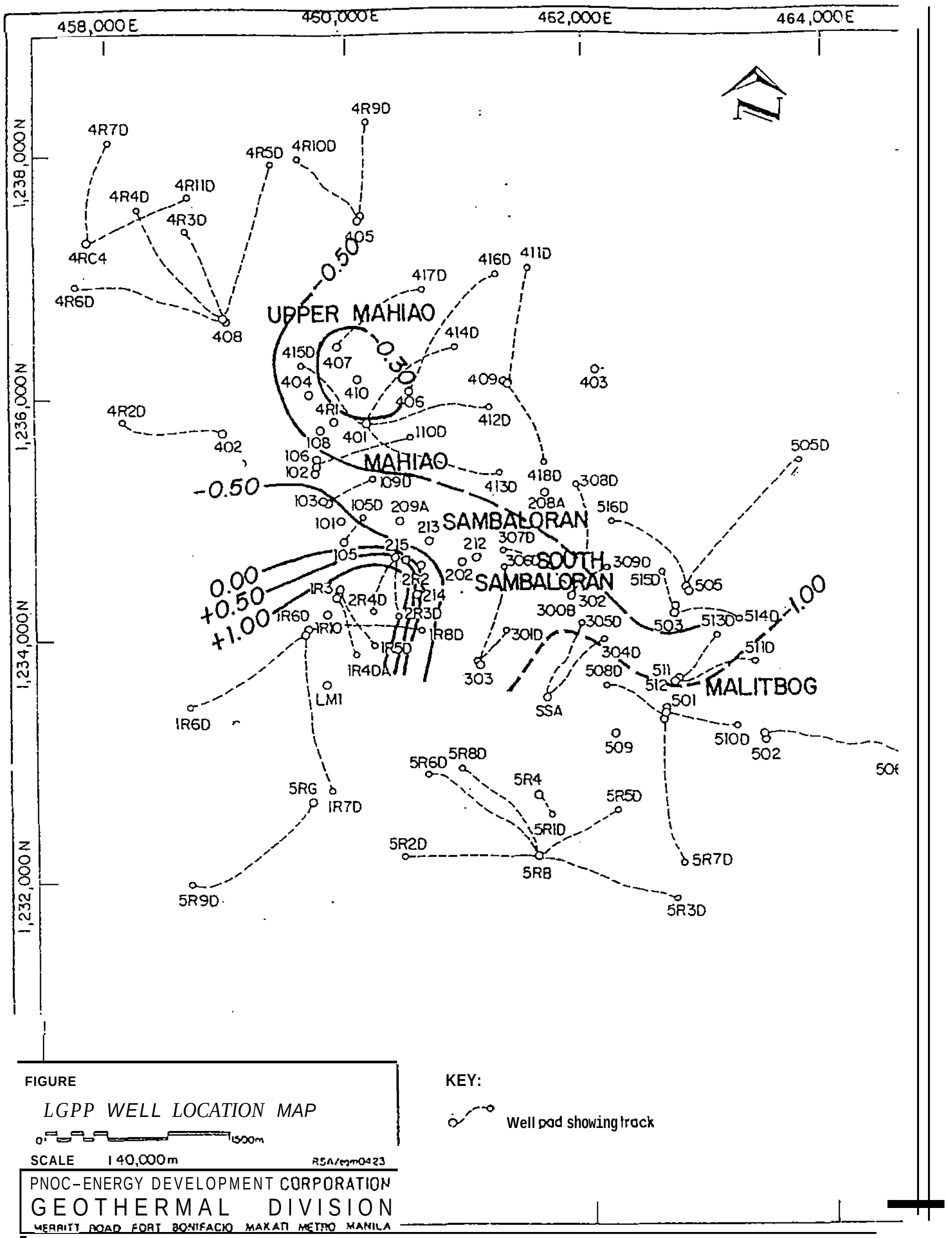
3.3 Iso-$\delta^{18}O$ Field Contour

The mass of reinjected waters **migrating** to the production wells of Mahiao and **Sambaloran** sectors is illustrated in the present **iso-$\delta^{18}O$** contour map across the Tongonan geothermal field (Fig. 9). There is an apparent identation of enriched $\delta^{18}O$ contour line corning from the reinjection sink unto the production sector. These cooler and highly mineralized waters are affecting the wells situated **within** the 1.5 km **radius** of the sink. The northern production wells are still enclosed **by** the isotopically enriched contour related with the parent fluids of Tongonan geothermal field at Upper Mahiao sector. Moreover, the contour shows that these steam-dominated wells are apparently not affected **by** the migration of the reinjected waters.

4.0 CONCLUSIONS

The trends in the stable isotope composition of the production wells and reinjection lines during the production phase in Tongonan-1 Production Field (T1PF) have provided evidences for two general reservoir processes, namely, the migration of the reinjection fluids from the reinjection sink to the production sector, and ***steam*** addition due to localized liquid reservoir drawdown.

The entry of the reinjection fluids in the production sector of T1PF is manifested on the enrichment of **heavy** isotopes and Cl, in the well waters. This process is **also marked by** the decline in $T(SiO_2)$, CO_{2td} and discharge enthalpy. The process is evident on the wells with liquiddominated and **two-phase fluids** situated within 1.5 km radius of the reinjection sink. On the other **hand,** steam addition induced **by localized** liquid reservoir drawdown is reflected on the incoherent trends in $\delta^{18}O$ and $\delta^{2}H$ values of the vapour-dominated wells. The initial influx of reinjection fluids in these wells is evident on the chemical and physical changes but is not clearly reflected on the changes in stable isotopes.



ACKNOWLEDGEMENTS

The authors wish to thank **IAEA** for the isotopic analysis **of** the samples and the staff and personnels of PNOC-EDC Geoscientific Dept. for their support in the compilation of the stable isotopes **data** since **1983.**

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