Isotopic Response to Changes in the Reservoir in Bacman Geothermal Production Field, Philippines

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ABSTRACT

The Bacman Geothermal Production Field typifies a liquid-dominated system. The Osiao-Pangas (OP) wells, located in the Botong area, tap the center of the resource and encounter fluids that are already products of boiling the parent water. The parent water, which closely resembles OP-4D, has an isotopic composition of: $\delta^{18}O \approx +2.0\ ^{o}/_{oo}$ and $\delta^{2}H \approx -26.0\ ^{o}/_{oo}$. The fluids at the upflow are isotopically enriched ($+4.0\ ^{o}/_{oo}$) and become depleted ($-3.9\ ^{o}/_{oo}$) as they outflow towards north-northwest in the central Palayang Bayan, and southwest in the Cawayan sector. The fluids along the outflow path are products of the dilution between meteoric waters and the parent water.

After eleven years of production, the most prominent processes occurring in the reservoir are boiling and dilution. Isotopic trends indicate that the central Palayan Bayan sector has been diluted with fluids coming from the western part. This fluid, also known as the Masakrot fluid, is isotopically depleted, slightly cooler, less mineralized and has lower gas and boron contents. The effect of dilution is manifested by the depletion of ^{18}O and ^{2}H in the central wells. The OP wells, on the other hand, are showing enrichment in the isotopic composition. As pressures draws down, these wells experience boiling in the reservoir.

1. INTRODUCTION

Bacman Geothermal Production Field (BGPF), one of the producing fields of PNOC-EDC lies in Bicol Region of eastern Philippines (Fig.1). Three power plants are currently installed at the production field and these supply the Luzon grid of Northern Philippines. A total of 150 MWe is supplied by the 20 production wells to these power plants.

Production in the field commenced in 1993, with the three power plants on line. Just like any other geothermal field, upon the start of commercial operations, changes started to occur. PNOC-EDC, being the operator of the field, closely monitors these changes as these have implications in the capacity of the field to produce.

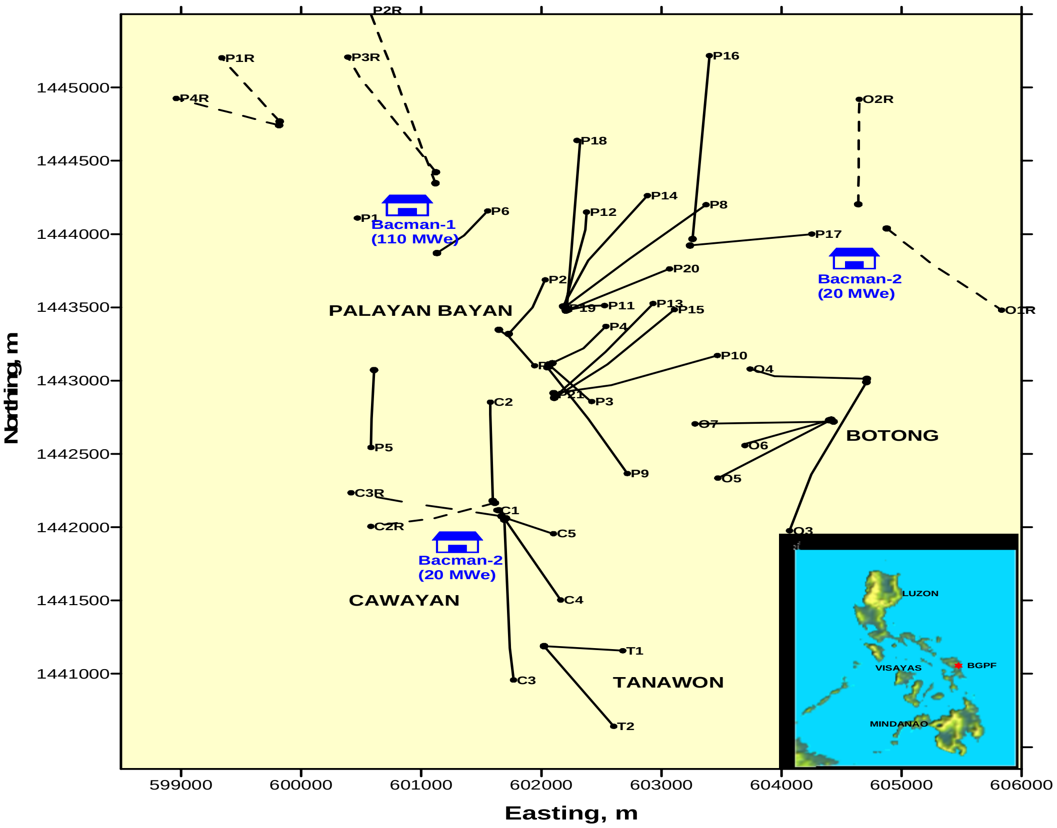

Figure 1: Bacman Geothermal Production Field location map of production wells (bold lines), reinjection wells(dashed lines) and power plants. Inset map shows location of BGPF in Philippine Archipelago.

The chemical as well as the physical variations (e.g. massflow, wellhead pressure (WHP), enthalpy) of each production well is being monitored on a regular basis. One geochemistry technique that has been proven to be helpful in field monitoring is using stable isotopes. Apart from isotopic data, other conventional geochemical monitoring tools are utilized for a holistic interpretation of the reservoir. Strategies for fieldwide management are based on the results of the monitoring.

This report will discuss the application of stable isotopes in BGPF. By monitoring the variations of the stable isotopes $\delta^{18}O$ and $\delta^{2}H$ and the fluids from wells, the processes occurring in the reservoir are detected. Water samples prior to 1996 were analyzed at the Institute of Geological and Nuclear Sciences at Lower Hutt, New Zealand; Center for Application of Isotopes and Radiation (CAIR) in Indonesia; and at the IAEA laboratory in Vienna, Austria. The isotope samples from 1996 to 2004 were already analyzed at the PNOC-EDC stable isotope laboratory in Manila.

2. PRE-EXPLOITATION ISOTOPIC CHARACTERISTICS

Figure 2 shows the pre-exploitation isotope content of the production wells. The $\delta^{18}O$ vs $\delta^{2}H$ of the wells were plotted with the local meteoric water line of BGPF (Olivar, et al, 2002). The plot shows a positive oxygen-18 shift from the local meteoric water line for all the wells. Moreover, the distribution of the wells defines a regression line with an equation of: $\delta^{2}H = -0.61 * \delta^{18}O - 25.2$. This line, which represents the mixing between two members, implies that the BGPF reservoir is a product of mixing between two types of water. One end could represent meteoric water (point A) while the other could be andesitic/magmatic water (point B), earlier postulated by Giggenbach (in Solis, et al, 1994). The varying degrees of mixture between these two waters brought about the differences in the isotopic content of the wells.

The variations in the mixture between the magmatic water and the meteoric water are directly correlated to the distribution of the wells in the field. The wells nearest the upflow or source of deep fluids have the greater isotopic content. The wells located at the margins of the field, or those that have encountered the outflow of the deep fluids, are more depleted. This is due to the greater fraction of meteoric waters already mixed with the outflowing geothermal fluids.

The $\delta^{18}O$ contour illustrates the isotopic variation across the field (Fig.3). The most enriched zone is centered across the OP wells in Botong at 0 to +4.0 $^{o}/_{oo}$. It becomes depleted towards Palayan Bayan at -1.0 $^{o}/_{oo}$ and from the Cawayan sector to as low as -3.26 $^{o}/_{oo}$. A Similar trend is observed with the reservoir chloride (Clres) content of the fluids. The highest Clres values are centered in the Botong area. The fluids become less mineralized towards the west and northern part of the field (Fig. 4).

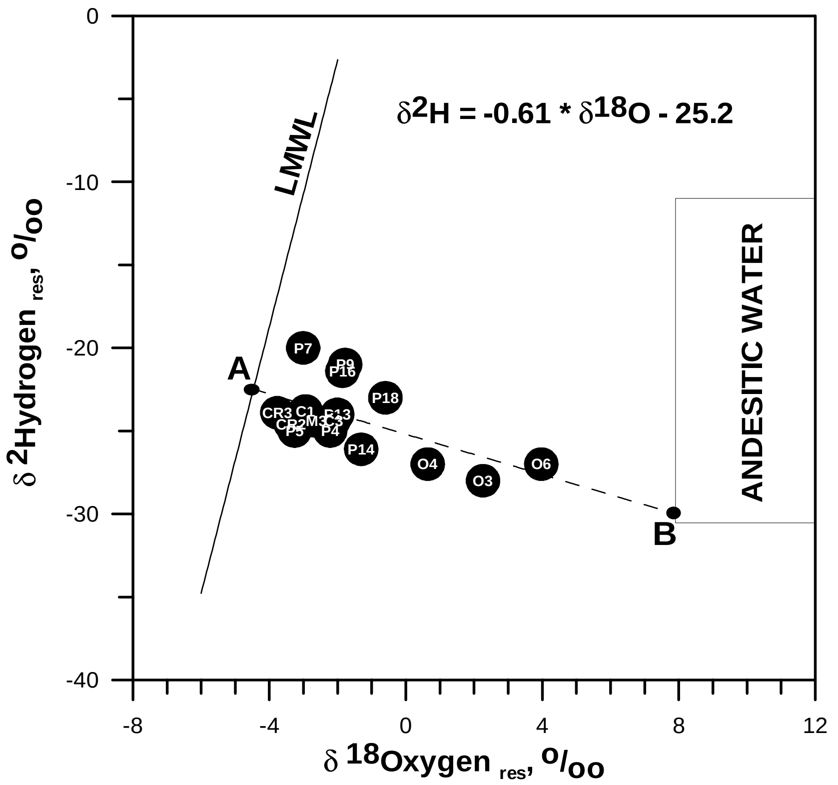

Figure 2: Isotopic composition of Production wells showing postulated zone of "andesitic waters". Points A and B are meteoric and "andesitic" endmembers, respectively. P-Palayan Bayan wells; O-Botong wells

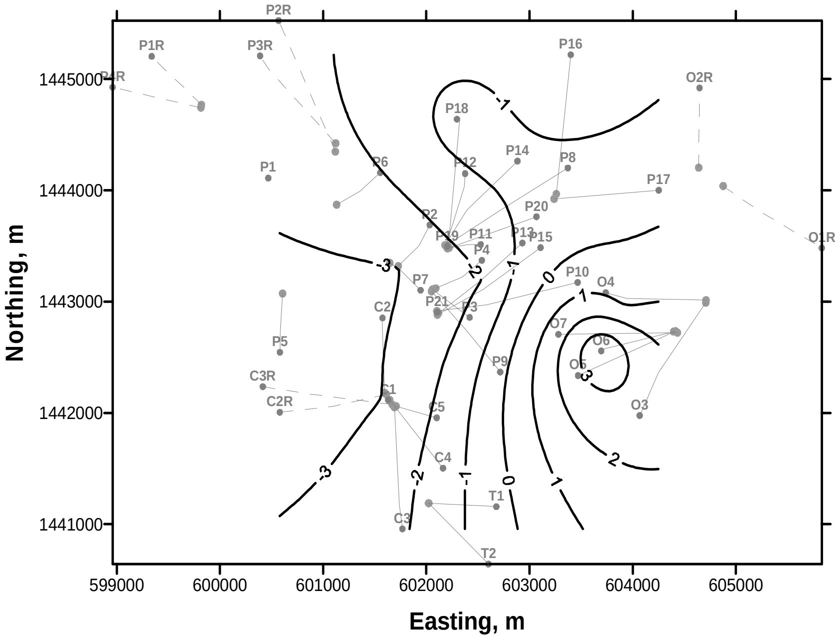

Figure 3: Contour of Oxygen-18 prior to exploitation

The extent of the isotopic shift of the well fluids from the LMWL may also be a function of the fluid temperature. Lesser isotopic shift may indicate a cooler well fluid temperature due to its higher meteoric water component. Well fluids that exhibit greater isotopic shifts, like OP-4D, have higher temperatures. Tquartz contour (Fig. 5) indicate that the hottest part of the reservoir is within the Botong area and temperature drops going north and west of the field.

Figure 6 shows the Chloride vs Enthalpy plot for the production wells in their natural state. Based on the plot, there appears to be three distinct clustering of wells. The OP-6D, CN-3RD and CN-2RD wells are grouped together, while the majority of the other wells represent one cluster. OP-3D is distinctly separated from the two groups. Each cluster defines a line which when extended converges to a point with an approximate enthalpy value of 1600 kJ/kg and reservoir chloride of 8000 mg/kg. This point of convergence could represent the parent water (PW in the plot) of the resource. Each line actually represents a reservoir process, based on their chloride and enthalpy values. Well OP-3D represents the boiling line; while wells OP-6D, CN-2RD and CN-3RD represent the wells tapping steam-condensate. The biggest cluster of wells defines the normal dilution line, where OP-4D shows the closest characteristic to the parent water.

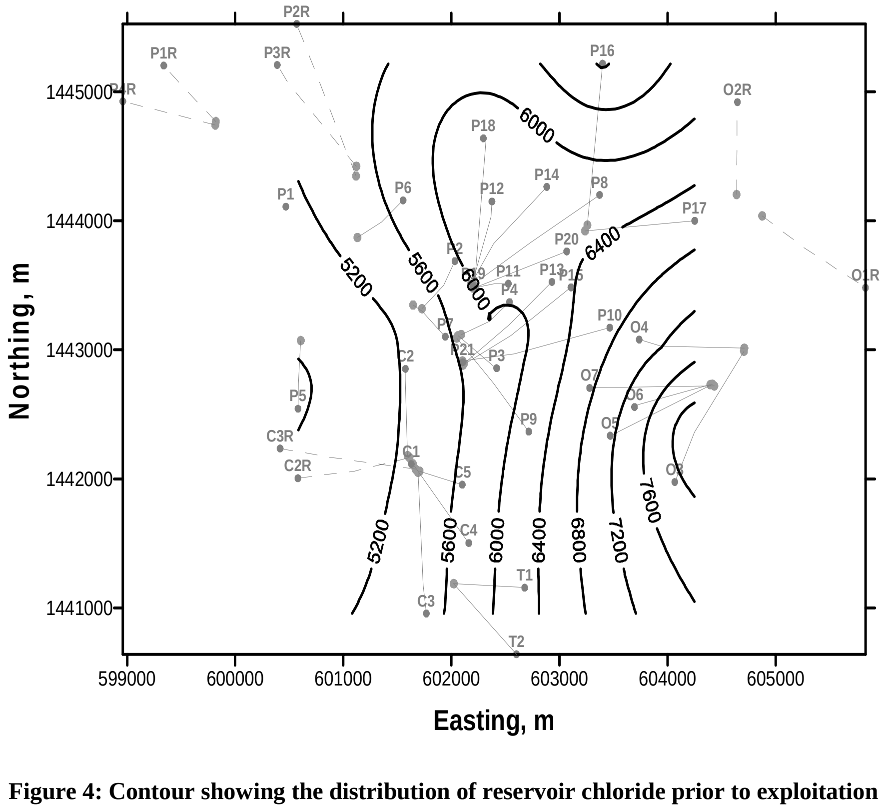

Figure 4: Contour showing the distribution of reservoir chloride prior to exploitation

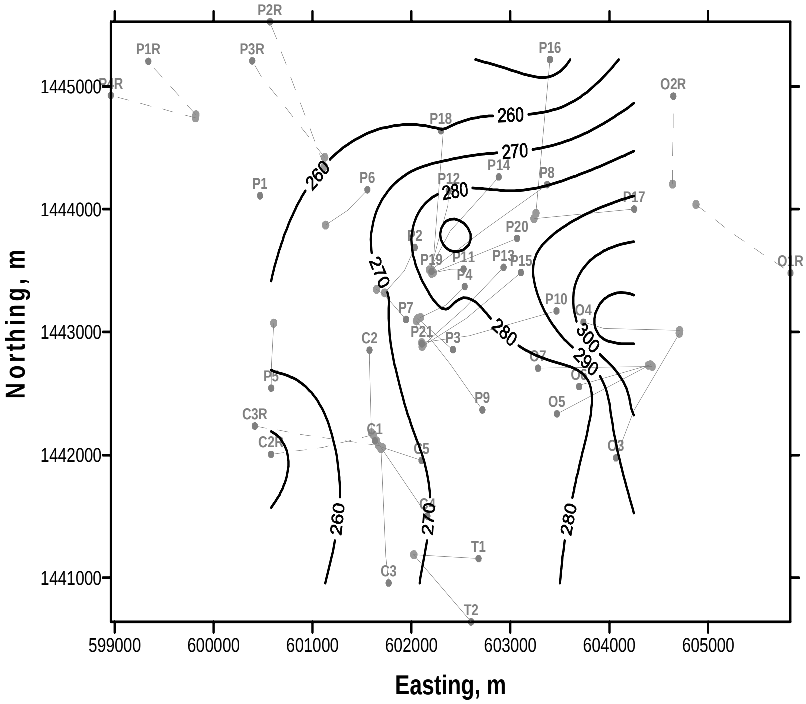

Figure 5: Contour of field temperature based on Quartz geothermometer prior to exploitation

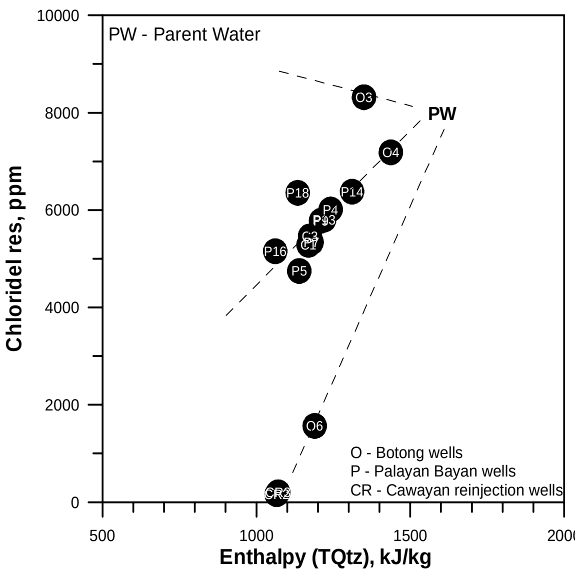

Figure 6: Chloride vs Enthalpy diagram of production wells

Well OP-4D has the highest fluid reservoir temperature (Appendix) among the wells. This implies that the center of the resource is upflowing beneath this well. The fluids then outflow in two directions. One outflow is towards the area of OP-3D in the east and the other is towards the Palayan Bayan where most of the wells are situated. As the fluids flow towards the vicinity of OP-3D, boiling also occurs. This is the reason why it has a higher chloride and oxygen-18 content than OP-4D.

3. RESPONSE TO COMMERCIAL PRODUCTION

During the first seven years of production (1993-2000), there was an obvious change in the isotopic content of the production wells. The $\delta^{18}O$ contour of the wells for the year 2000 is shown in Figure 7. The most enriched section is still the Botong area and the waters still become depleted towards the Palayang Bayan and Cawayan sectors. However, the $-2.0^{o}/_{oo}$ contour already advanced into the central Palayang Bayan sector. Moreover, there is a steep gradient between the Botong sector and the central Palayang Bayan sector. This could mean that the isotopically depleted fluid from the Cawayan sector is encroaching the central Palayang Bayan sector.

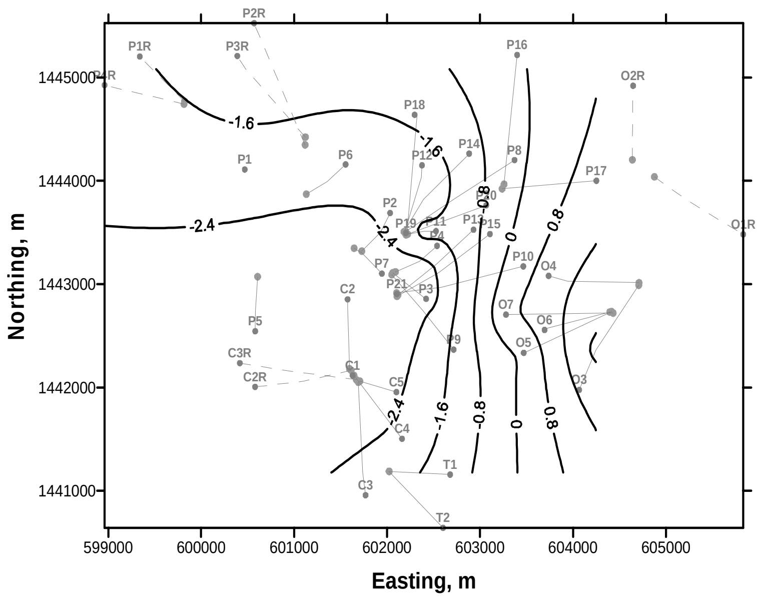

Figure 7: Distribution of oxygen-18 across the field for the period of 2000

The Clres vs $\delta^{18}O$ plot (Fig. 8) shows the plot of both pre-exploitation and the isotope data of the wells in 2000. Based on the plot, the parent water (PW) is inferred to have an oxygen-18 value of approximately $+2.0^{o}/_{oo}$ by extending the dilution line at reservoir chloride of 8000 mg/kg (based on Figure 6). Earlier reports (Solis et al, 1993; Ruaya, et al, 1994) also infer that the parent water has an oxygen-18 value of approximately $+2.0^{o}/_{oo.}$ Figure 8, likewise, shows the changes that some of the wells have undergone since the start of production in the field. There is an apparent change in the chemistry of some of the wells like PAL-18D and PAL-14D. There is depletion in $\delta^{18}O$ and a slight increase in Clres. The change in chloride, however, could just be within errors. The depletion in these wells is attributed to the incursion of the Masakrot fluids coming from the western part to the central part of the resource. Chemical monitoring revealed that the wells affected by this fluid, experienced decline in boron and temperature (Maturgo, et al, 2000).

On the other hand, among the Botong wells, OP-3D has shown enrichment in oxygen-18. Well OP-3D increased its value from $+2.26^{o}/_{oo}$ (pre-exploitation) to $+2.59^{o}/_{oo}$ (2000). There is also a noticeable increase in chloride. OP-5D and OP-7D also have very high chloride, although their oxygen-18 values are relatively similar to pre-exploitation values of OP-4D. This change in chemistry clearly denotes boiling. Boiling enriches the residual liquid while at the same time depleting the steam produced. The isotope data suggests that the wells are still tapping the liquid reservoir, albeit excessive boiling in this area. The continuous boiling in this part of the reservoir will eventually expand the vapor zone above.

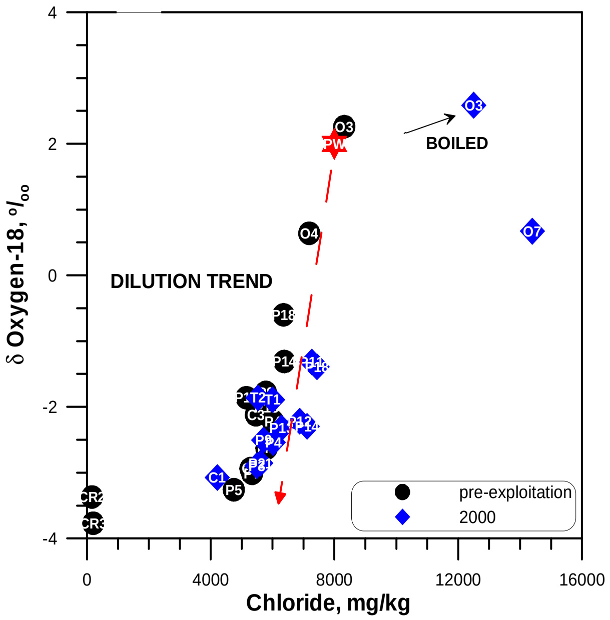

Figure 8: Plot of reservoir chloride and oxygen-18 of production wells showing changes from pre-exploitation to 2000. Included in the plot are Tanawon wells(T).

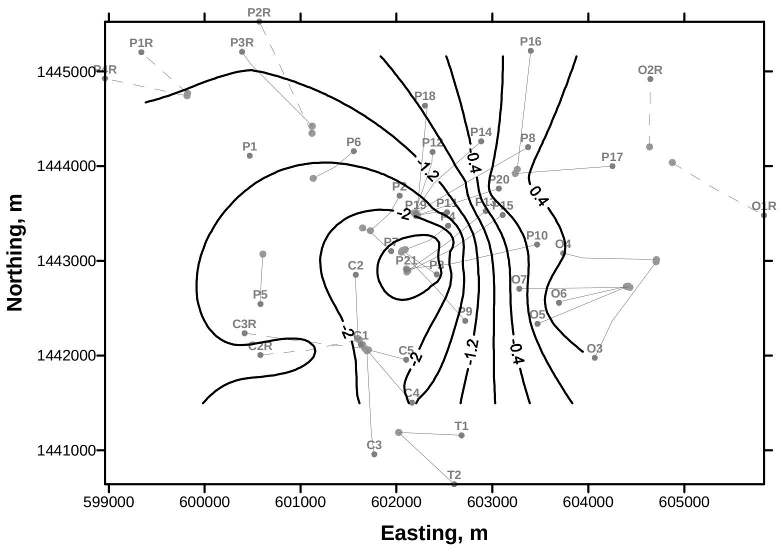

Figure 9: Distribution of oxygen-18 across the field for the period of 2004

The expansion of the vapor zone in the Botong area is apparent already in the 2004 isotope data. The contour of $\delta^{18}O$ (Fig. 9) during the period shows significant depletion in the vicinity of Botong. OP-6D, which is highly enriched at the start (at $+3.97^{o}/_{oo}$), has depleted significantly to just $+0.72^{o}/_{oo}$. This depletion could greatly imply that this well is already tapping the upper steam cap, and not just the two-phase zone. The very high enthalpy of well OP-6D, almost reaching that of a pure steam (2455 kJ/kg), clearly points to the presence of the steam cap.

The OP-4D isotope value of $+0.46^{o}/_{oo}$ and enthalpy of almost 2000 kJ/kg, indicate that the level of the liquid reservoir in this part of the field has already decreased and that the two-phase zone above has expanded. Among the Palayan Bayan wells, PAL-20D is already tapping the two-phase zone based on its discharge enthalpy of 1968 kJ/kg and oxygen-18 value of $+0.26^{o}/_{oo}$. This means that not only is there a vertical expansion of the two-phase zone but lateral migration is also occurring.

There is still the movement of the Masakrot fluid towards the central part of the field, particularly in the vicinity of Palayan Bayan wells (i.e. PAL-13D, PAL-11D). However, very slight depletion in the isotope values is being observed. Only PAL-11D showed a noticeable drop in values.

Enrichment in isotope values is observed in the reinjection wells (PAL-1RD, CN2RD). From a value of $-3^{o}/_{oo}$ in 2000, CN2RD has significantly become enriched to $-1.6^{o}/_{oo}$. This increase or enrichment is actually just attributed to the characteristic of reinjected fluids. Separation of steam from the brine in the flash vessels produce enriched separated waters, which are injected back to the reservoir. Consequently, the fluids collected or sampled from the reinjection wells are already enriched.

Based on the Clres vs $\delta^{18}O$ crossplot of all the production and reinjection wells for 2004 (Fig. 10), there doesn't seem to be any problem with reinjection fluid encroachment into the reservoir. Both the Clres and isotopic values of the production wells are similar to that of the reinjection wells PAL1RD (P1R in plot) and CN2RD (C2R in plot). In fact all the wells belong to the same dilution path, which suggests that same reservoir process apply to these wells. However, the possibility of reinjection fluid encroachment in the production zone should not be discounted. This is expected since there is continuous movement of the western fluids towards the reservoir.

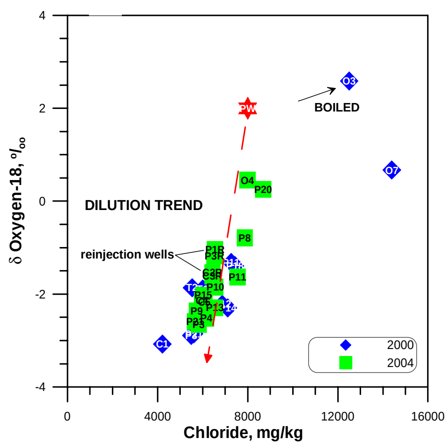

Figure 10: Crossplot of oxygen-18 and chloride of production and reinjection wells, 2000 vs 2004

4.0 CONCLUSIONS

The Bacman geothermal field typifies a liquid-dominated system, with an upflow zone defined by the most mineralized and hottest wells. Cooler and less mineralized waters characterize the outflow of the system. The isotopic composition of the fluids, likewise define a gradation from the upflow to the margins. The fluids at the center of the resource are isotopically enriched while wells located at the margins are more depleted (Fig. 11).

Continuous extraction alters the natural state of the field. The Masakrot fluid continuously moves eastward due to pressure gradient caused by continuous discharge of fluids. As of this writing, however, there is still no indication of a large-scale pressure drawdown that could drastically affect the reservoir. The steam cap at the upflow continues to expand as boiling naturally occurs. This vapor zone and highly two-phase zone are presently what the wells at the center of the resource tap. Operationally, this does not pose any problem to field management. If at all, excess steam are produced which increase the field production.

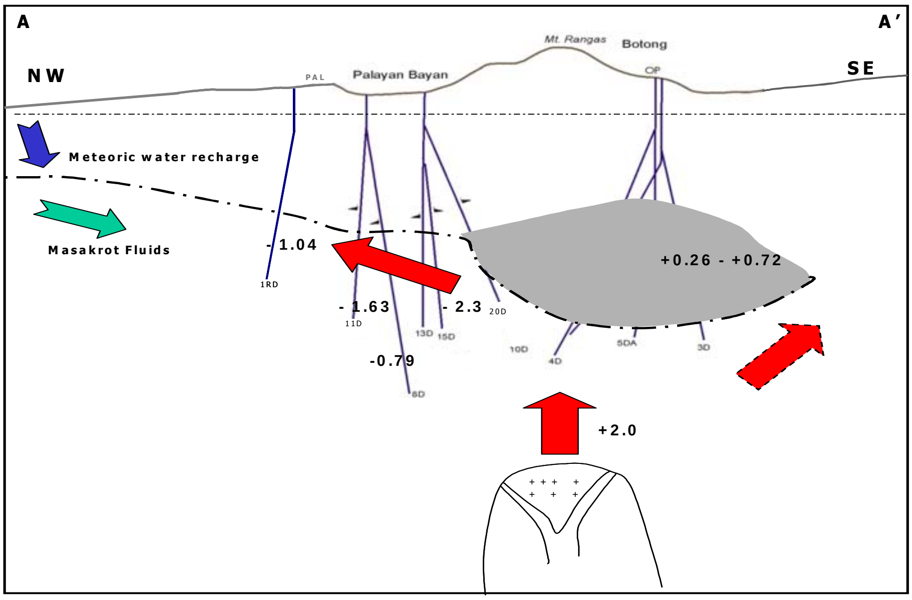

Figure 11: Present day configuration and fluid flow paths of BGPF reservoir, showing $\delta^{18}O$ values ($^{o}/_{oo}$)

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Appendix: Selected Chemistry of Selected Production and Reinjection Wells

Well	Sampling Date	Enthalpy, kJ/kg	Tquartz, °C	Chloride res, mg/kg	$\delta^{18}O$ res, $^{o}/_{oo}$	^{2}H res, $^{o}/_{oo}$
PAL3D	17-Apr-00	1286	268	5493	-2.89	-23.6
	07-Jan-04	1210	261	5826	-2.65	
PAL11D	18-Apr-00	1770	274	7266	-1.32	-23.7
	15-Jan-04	1751	269	7553	-1.63	
PAL13D	13-Aug-93	1220	277	5804	-2.01	-24.0
	10-Apr-00	1501	271	6292	-2.32	-25.2
	08-Jan-04	1303	278	6543	-2.29	
PAL20D	15-Jan-04	1968	274	8687	0.26	
PAL21	17-Apr-00	1253	262	5612	-2.85	-22.9
	08-Jan-04	1096	261	5663	-2.59	
OP3D	27-Aug-91	1350	301	8318	2.26	-28.0
	20-Apr-00	2455	308	12503	2.59	-24.6
OP4D	19-Jun-91	1437	316	7186	0.64	-27.0
	13-Jan-04	1940	301	7989	0.46	
OP6D	04-Sep-91	1190	271	1566	3.97	-27.0
	16-Jan-04	2455	281*	-	0.72	
CN2RD	07-Jun-91	966	162	246	-3.37	-24.6
	03-Apr-00	707	175		-1.85	-22.6
	19-Jan-04	707	175	6437	-1.54	
PAL3RD	03-Apr-00	741	175		-1.02	-20.3
	16-Jan-04	741	175	6527	-1.18	

* Temperature based on H_2S-CO_2 geothermometer