GAS EQUILIBRIA IN TONGONAN, MAHANAGDONG AND ALTO PEAK GEOTHERMAL FIELDS, LEYTE, PHILIPPINES

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ABSTRACT

The state of gas equilibria in the production wells and the natural thermal areas of Tongonan, Mahanagdong and Alto Peak geothermal fields in Leyte was analysed. Three approaches were applied: the first one involves equilibria of H_2 and Ar in gases (Giggenbach, 1980); the second one involves the breakdown of ammonia; and the third one is the breakdown of methane or the Fischer-Tropsch reaction (D 'Amore et al., 1993).

The results of the studies showed that the parent fluids in Tongonan geothermal field consist mostly of liquid phase with reservoir temperature of 310-320°C. The thermal area of Kapakuhan also showed similar temperature indicating that the gases in the fumaroles were directly derived from the first boiling of the parent fluids. The fluids migrating towards the outflow in Malitbog sector have lost 5.0% of the original steam and have re-equilibrated at temperature of 240-270°C. In Bao-Banat-i thermal areas, which mark the outflow of the reservoir, the fluids were derived from liquid reservoir with temperature of about 180°C. The present production wells of Tongonan-1 showed two gas trends. Those wells lying proximate to the upflow area in Upper Mahiao have gained steam which was possibly induced by pressure drawdown. On the other hand, the production wells lying close to the reinjection sink showed steam loss of about 2.0 to 5.0% due to mixing of degassed reinjected fluids.

In Mahanagdong, the parent fluids have temperature of 310°C, which is reflected in the H_2/Ar geothermometer of Mahanagdong fumarole. The two-phase fluids in the upflow zone have gained vapours by as much as 5.0%. The fluids in the outflow sector have lost 7.0% of the original vapour and re-equilibrated in reservoir temperature of 240-260°C. The acid wells in the north also showed vapour gain by as much as 50% which is explained by incomplete equilibration of the original magmatic gases with the reservoir rocks. On the other hand, the gain of 1.0% vapour in a cold well in the west can be attributed to the inflow of cooler steam condensates.

In Alto Peak, the Danglog solfatara indicate temperature of greater than 370°C, or that of a magmatic environment. All of the wells showed vapour gain from 1.0 to 50.0% attesting to the vapour-rich nature of the Alto Peak fluids. This can be an inherent characteristic of a magmatic system presently evolving into a hydrothermal system.

1.0 INTRODUCTION

Tongonan, Mahanagdong and Alto Peak geothermal fields lie ensconded between the two segments of the Philippine fault in central part of Leyte island, Philippines (Fig. 1). These three fields represent three distinct geothermal systems of varrying age and geochemical characteristics. Tongonan field hosts a 10 km^2-wide commercial reservoir with an age of at least 5,500 years (PNOC-EDC, 1993). Since 1983, the 112.5 Tongonan-1 power plant has been operating in Tongonan field. Mahanagdong reservoir, whch covers about 6.5 km^2 area is estimated to be of the same age as Tongonan. Alto Peak field has a young age of 2,700 to 6,000 years (Takashima et al., 1996).

The primary objective of this paper is to analyse the gas equilibria of the above three geothermal fields and reconcile the results of the *study* with their known ages and with their established hydrothermal flow models. It is also the objective of this paper to use gas equilibria in determining the reservoir processes as well as the reservoir changes brought about by the commercial operations.

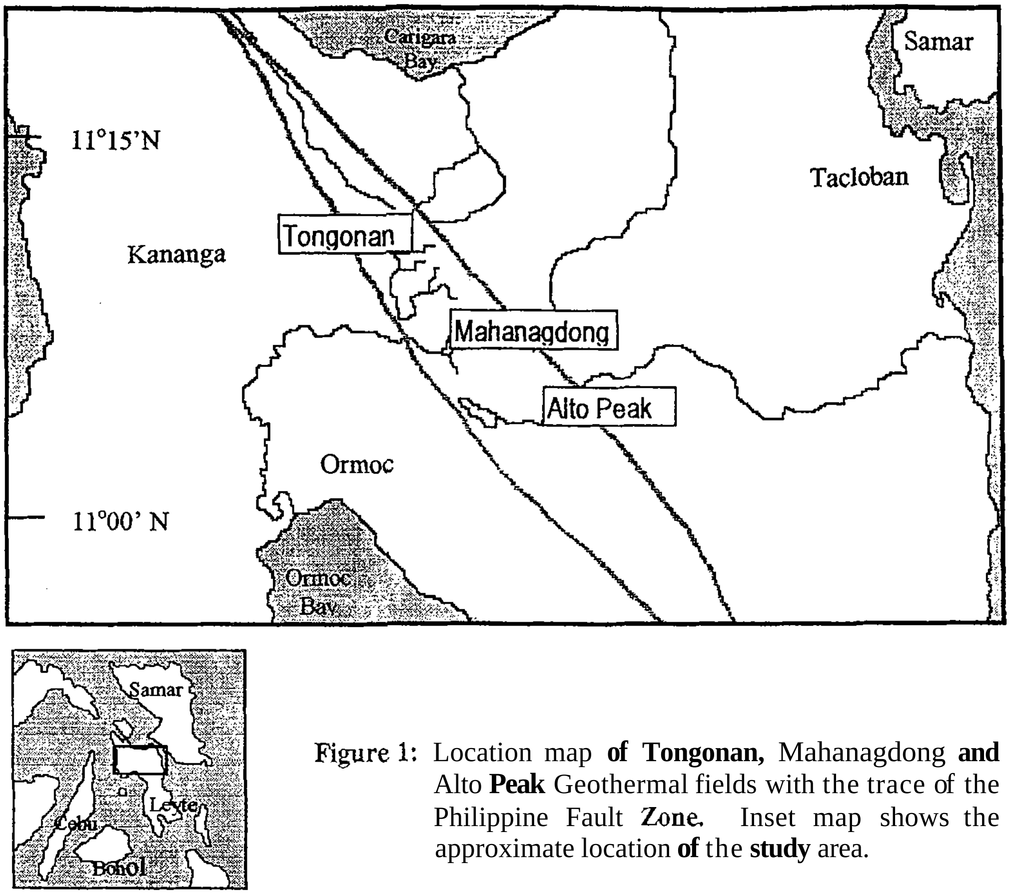

Figure 1: Location map **of Tongonan,** Mahanagdong **and** Alto **Peak** Geothermal fields with the trace of the Philippine Fault Zone. Inset map shows the approximate location **of** the **study** area.

2.0 THEORETICAL BASIS

The following sections were condensed, to some extent lifted, from existing publications on gas equilibria. These serve as the guiding theories of this paper.

2.1 H_2-Ar Equilibria

Of the geothermal gases, H_2 reacts most quickly to changes in temperature and redox conditions (Giggenbach, 1980). In fact, the apparent success of most gas geothermometers is attributed to the rapid response of H_2, thus cancelling out the variations in any of the other components involved. On the other hand, Ar is chemically inert and is introduced almost exclusively with the meteoric water recharges. Owing to these characteristics, the molar ratios of H_2/Ar will not only reflect the equilibration temperature, but also the dilution and boiling processes which have occurred to the gas samples. The temperature dependence of the H_2/Ar mole ratio in the equilibration liquid phase corresponds to:

$$T(H_2/Ar) = 70 \times [2.5 + \text{Log}(H_2/Ar)] \qquad \textit{Eqn. 1}$$

In **liquiddominated** geothermal system, chemical equilibration takes place largely in dissolved form even among gaseous constituents. During the first boiling, H_2 and Ar virtually partition into the first vapour formed because of their very low solubilities. It can thus be assumed that the H_2/Ar ratios of the surface samples represent that of the deeper environment.

2.2 Ammonia Equilibria

The ratios of the common geothermal gases may be controlled by several reactions. One of these reactions is the breakdown of ammonia to nitrogen and hydrogen as shown in the following equations:

$$2NH_3 \longrightarrow N_2 + 3H_2 \qquad \textit{Eqn. 2}$$

Applying the law of mass action and following all gas constants and partitioning coefficients (Giggenbach 1980; D'Amore et al, 1982; D'Amore and Truesdell, 1985 and 1988), the following equation can be derived (D'Amore et al., 1993):

$$\begin{aligned} HN &= 0.5Log(N_2/H_2O) + 1.5\,Log(H_2/H_2O) - Log(NH_3/H_2O) \\ &= 0.39 - 652/T + f_1(y,B_i) \qquad \textit{Eqn. 3} \end{aligned}$$

where temperature T is in °K; y is the in-situ steam fraction (y has positive value when a fraction of steam is present at equilibrium with the liquid phase but has a negative value when a fraction of steam is irreversibly lost from the original liquid); and B_i is the vapor-liquid distribution coefficient, a known function of temperature. The following equations were used for positive or negative y values to link with the physical parameters in the reservoir:

$$\begin{aligned} \text{for } y>0:\ HN &= 0.39 - 653/T + 0.5Log[y+(1-y)/B_{N2})] \\ &\quad + 1.5Log[y+(1-y)/B_{H2}] - Log[y+(1-y)/B_{NH3}] \qquad \textit{Eqn. 4a} \\ \text{for } y<0:\ HN &= 0.39 - 653/T - 0.5B_{N2} - 1.5B_{H2} + B_{NH3} \\ &\quad - 0.5Log[1+y-yB_{N2}] - 1.5Log[1+y-yB_{H2}] \\ &\quad + Log[1+y-yB_{NH3}] \qquad \textit{Eqn. 4b} \end{aligned}$$

2.3 Fischer-Tropsch Equilibria

Another chemical reaction which control gas ratios in geothermal environment is the Fischer-Tropsch reaction, or the breakdown of methane to carbon dioxide and hydrogen:

$$CH_4 + 2H_2O \longrightarrow CO_2 + 4H_2 \qquad \textit{Eqn. 5}$$

Again, using the mass action law, the following equation can be derived at equilibrium conditions involving the partial pressures of each gas species **as functions of** the concentrations at the discharge point, temperature, the distribution coefficient, and vapour fraction y (D'Amore et **al.**, 1993).

$$\begin{aligned} FT &= 4Log(H_2/H_2O) - Log(CH_4/CO_2) \\ &= -15.35 - 3952.8/T + 4.635\,LogT + f_2(y, B_i) \qquad \textit{Eqn. 6} \end{aligned}$$

The following equations were used for positive and negative y:

$$\begin{aligned} y>0:\ FT &= -15.35 - 3952.8/T + 4.635LogT \\ &\quad + 4Log[y+(1-y)/B_{H2}] + Log[y+(1-y)/B_{CO2}] \\ &\quad - Log[y+(1-y)/B_{CH4}] \qquad \textit{Eqn. 7a} \\ y<0:\ FT &= -15.35 - 3952.8/T + 4.635LogT - 4LogB_{H2} \\ &\quad - LogB_{CO2} + LogB_{CH4} - 4Log[1+y-yB_{H2}] \\ &\quad - Log[1+y-yB_{CO2}] + Log[1+y-yB_{CH4}] \qquad \textit{Eqn. 7b} \end{aligned}$$

3.0 RESULTS

The calculations based on the above equations are presented in this paper as graphs and **grids.** The quark geothermometer based on Fournier and Potter (1982) is used as reference temperatures for production wells and the measured field temperatures for the fumaroles. The line in the graphs with zero y is referred here as the equilibrium-liquid line. The equilibria involving dissolution of pynte or HSH (D'Amore et al., 1993) is not included in this paper because it was proven to be not applicable in Mahanagdong and Alto Peak geothermal fields. It was, however, proven effective in monitoring reservoir processes in Tongonan geothermal field (Salonga et al., 1996). The gas data used in this paper are shown in the attached Appendix.

3.1 Tongonan Field

The data point of Kapakuhan fumarole can be correlated with the wells in Upper Mahiao sector, that is the 400-series wells (Fig. 2) at reservoir temperature of 300-320°C. On the other hand, the Bao and Banat-i fumaroles, which are associated with the neutral-pH Cl springs, fall along the equilibrium-liquid line at temperature of about 180°C.

The postulated parent fluids in Tongonan is composed of wholly liquid-phase with temperature of around 320°C, represented by well 410 (Figs. 2, 3 and 4). Most of these wells plotted along and above the equilibrium-liquid line which represent about 1% vapur gain. Well 411D, however is an exception which instead plotted below the equilibrium-liquid line. Towards the southeast, that is in the general area of South Sambaloran (i.e., the 300-series wells) and Malitbog (i.e., the 500-series wells), the data points plot below the equilibrium-liquid.

The wells in Mahiao (i.e., 100-series wells) and Sambaloran (i.e., the 200-series wells) sectors have been supplying *steam* to Tongonan-1 power plant since 1983. Their data points are also shown in Figures 3 and 4. In the plots, the well which had increasing trend in discharge enthalpy, like wells 106, 108, 109 and 110D, plotted above the equilibrium-liquid line, translating to about 1.0 to 5.0% vapour gain. The wells which have lower discharge enthalpy, especially the 200-series wells, plotted along or below the equilibrium-liquid line indicating about 5.0% vapour loss.

3.2 Mahanagdong Field

Unfortunately, in Mahanagdong, there was no Ar analysis for the well gas samples obtained before 1995, thus only the fumaroles and selected wells are shown in Figure 5. Nevertheless, the Mahanagdong fumarole can be correlated to parent fluids with temperature of 310°C, while the Paril fumarole corresponds to deep reservoir fluids of 280°C. The postulated parent fluids of Mahanagdong, which has temperature of 320°C and almost zero y, is closely approximated by well MG-3D (Figs. 5, 6 and 7). In the graphs, the data point of MG-3D plotted above the equilibrium-liquid line, close to other wells with high aquifer temperatures and containing high levels of gases (i.e. MG-5D, 14D and 24D), representing about 0.5-5.0% in vapour gain.

The wells lying south of the high gas-wells (i.e. MG-7D, 13D, 16D, 17D, 18D, 19, 22D and 23D) plotted below the equilibrium-liquid line representing about 0.1-7.0% vapour loss. The group of acid wells lying north of MG-3D (i.e. MG-20D and 21D) shows *gain* in vapour by about 2% in FT equilibria and by as much as 50% in ammonia equilibria.

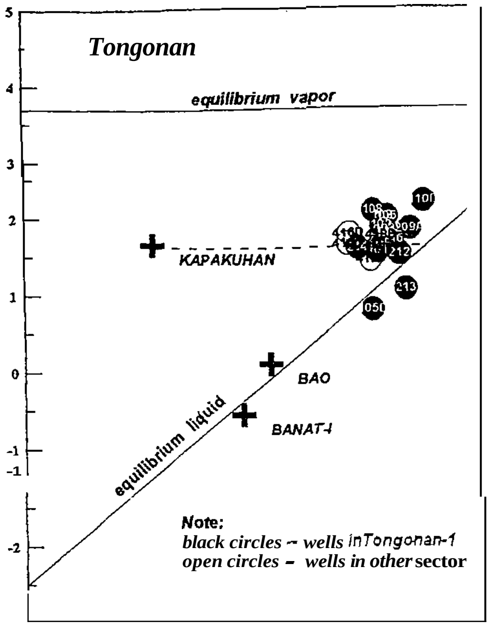

Figure 2: Plot of $Log(H_2/Ar)$ vs. $T(SiO_2)$ of Tongonan

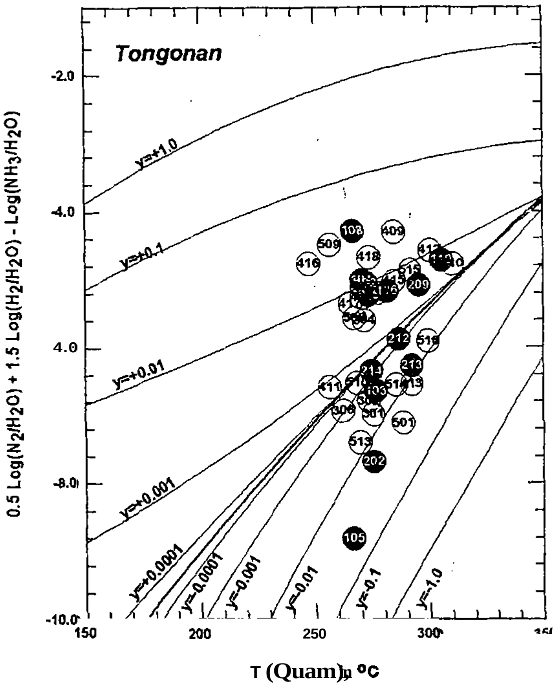

Figure 3: Plot of HN vs. $T(SiO_2)$ of Tongonan

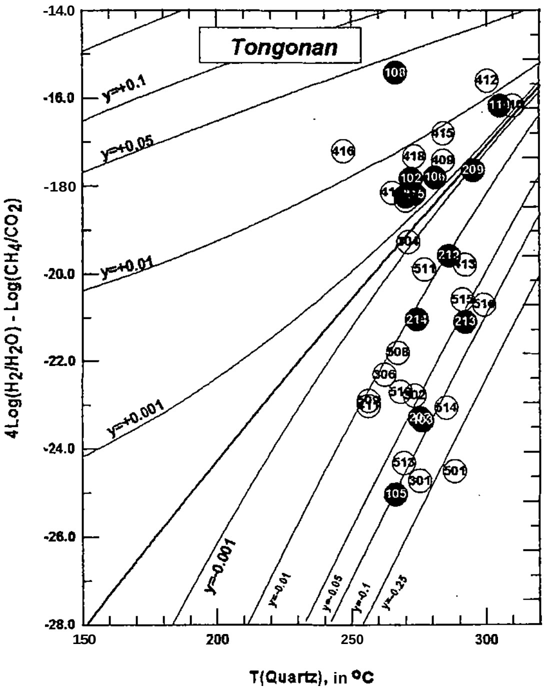

Figure 4: Plot of FT vs. T(SiO$_2$) of Tongonan

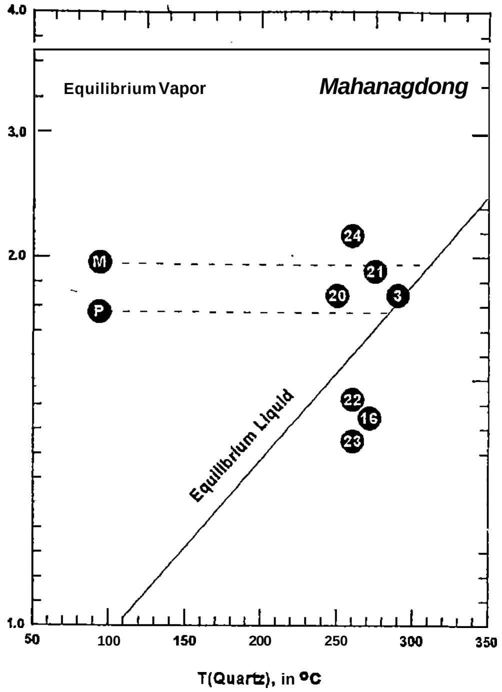

Figure 5: Plot of Log(H$_2$/Ar) of Mahanagdong. (Note: the prefix MG was removed in the wells)

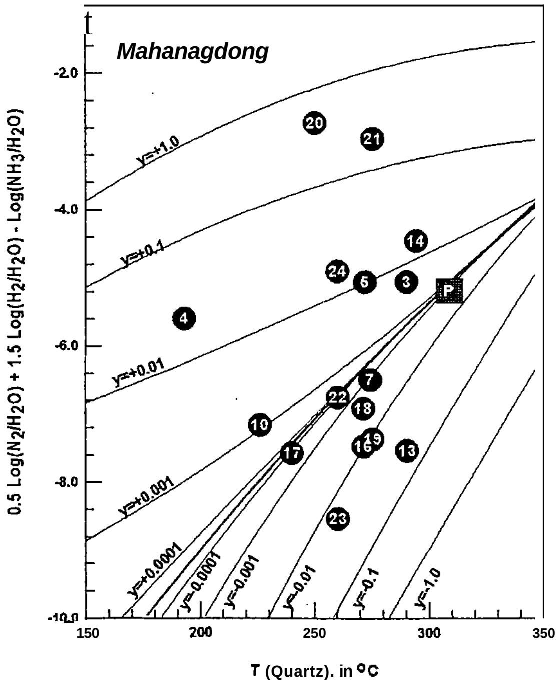

Figure 6: Plot of HN vs. T(SiO$_2$) in Mahanagdong.

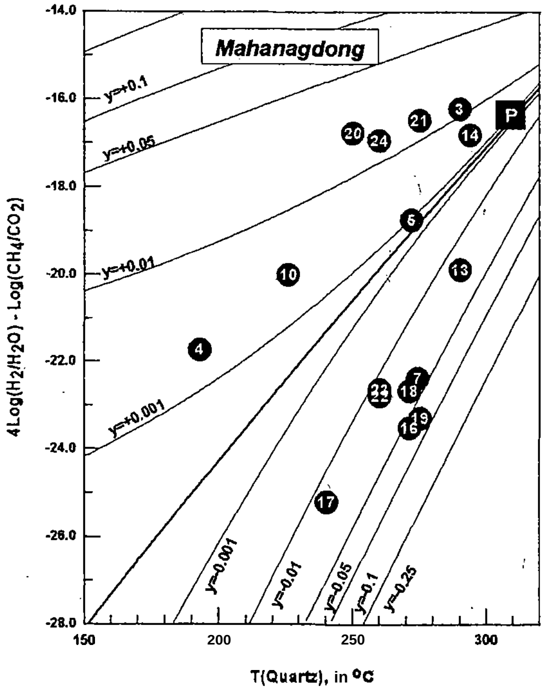

Figure 7: Plot of FT vs. T(SiO$_2$) of Mahanagdong

On the other **hand,** the peripheral wells of MG-4D, a well with cooler fluid inflow, and MG-10D, a well with very poor permeability, showed vapour **gain** of as much as 1.0%.

3.3 Alto Peak Field

The Danglog solfatara *can* be correlated with parent fluids having temperature of at **least 370°C** based on H_2/Ar geothermometer. This is above the critical temperature **of** water. *On* the other hand, the Tapol bubbling **pool** found on the periphery of Alto Peak volcanic edifice plotted near the equilibrium liquid line with temperature of **54°C** suggesting a shallow liquid-dominated reservoir feeding the bubbling pool (Fig. **8).**

The **data** points of Alto Peak wells generally plotted above the equilibrium-liquid line in the graphs of H_2-Ar, ammonia and FT **equilibria (Figs.8,** 9 and 10) indicating vapour gain of about 25% for AP-1D and 7D, 10% for AP-2D, and 1-5% for **AP-4D,** 5D and 8D. The fact that **all of** the wells have gained vapour attest to the gas-rich **nature** of the Alto Peak reservoir.

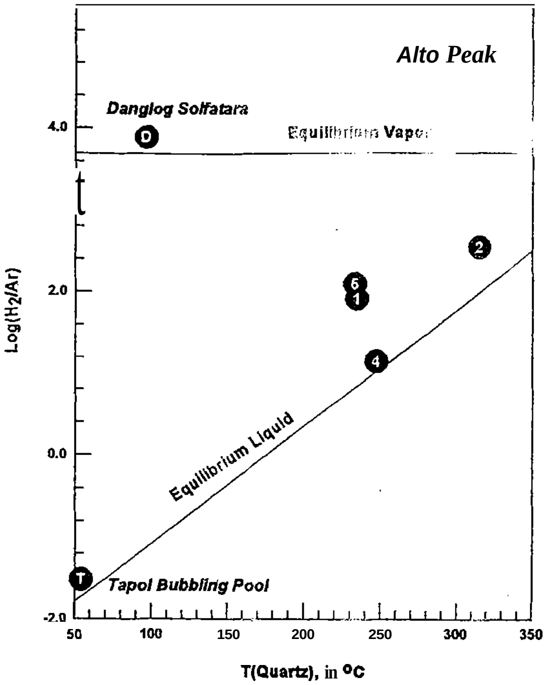

Figure 8: **Plot of $Log(H_2/Ar)$ of** Alto **Peak.** (Note that the prefix ***AP*** was removed from plots of wells).

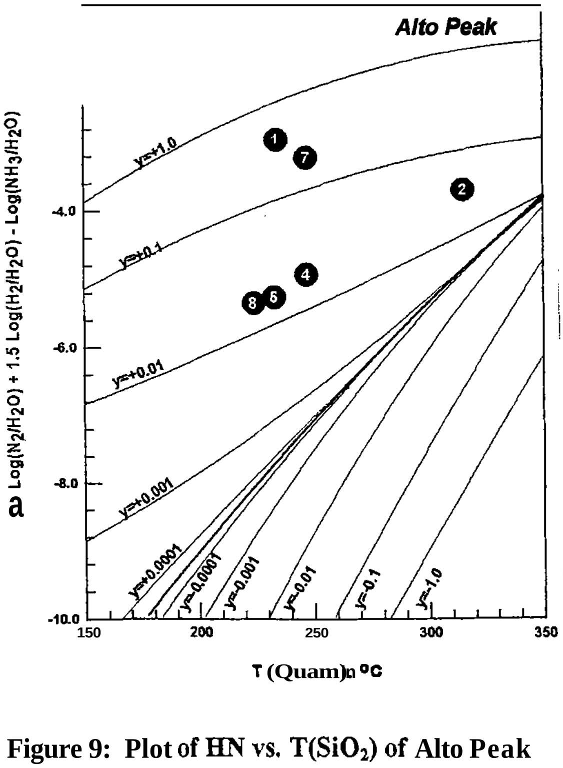

Figure 9: Plot of HN vs. $T(SiO_2)$ of Alto Peak

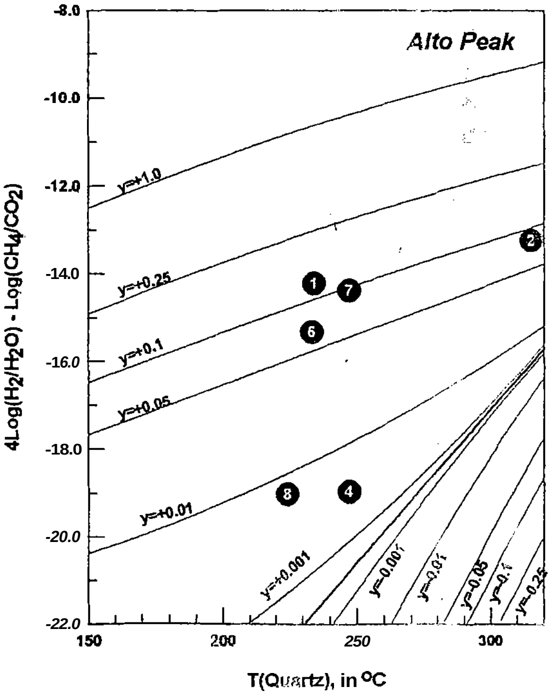

Figure 10: Plot of FT vs. $T(SiO_2)$ of Alto Peak

4.0 GENERAL DISCUSSION

4.1 Alto Peak Field

Alto Peak is an inactive volcano presently in the solfataric stage. The artifacts of volcanism in this andesitic terrain include the high level of gases in wells and thermal features which are higher by two orders of magnitude than the hydrothermal systems of Tongonan, Palinpinon and Mt. Apo (Salonga, 1996). Moreover, the Danglog solfatara indicated a temperature of greater than 370°C..This is above the critical temperature of water which can only be reflective of a magmatic environment.

Ammonia and FT equilibria indicated vapour gain in all production wells, including those wells with low discharge enthalpy like AP-4D and 5D. There could be two reasons for this. One is the presence of degassing intrusive bodies beneath Alto Peak whch provide fresh supply of magmatic gases. The geochemistry of wells AP-6D and 7D indicated the presence of magmatic fluids in the core of Alto Peak. Another reason is that the deep well discharges still retain the characteristics of the original magmatic fluids because they still have not attained MI-equilibrium with the reservoir rocks. Previous studies have shown that the permeability in Alto Peak is confined in the crater area and almost absent in the peripheral areas. This factor generated poorly interconnected reservoirs of thermal fluids, and poorly developed outflow zone. Because of this, the deep thermal fluids did not have the chance of fully equilibrating itself with the rocks.

4.2 Mahanagdong Field

The Mahanagdong reservoir can be viewed as composed of two geothermal systems, one is the neutral-pH system in the south, and the other one is the acid system in the north. The trace of "Mamban fault" separates the two systems. The acid wells showed vapour gain even though they do not have any excess enthalpy. This can be a similar case to wells AP-4D and 5D of Alto Peak which still retained the artifacts of the original magmatic fluids. It is therefore possible that the acid system in the north have still not attained full equilibration with the reservoir rocks owing to the undeveloped fluid flow system towards the north.

The H_2/Ar geothermometer of the Mahanagdong fumarole reflects the temperature of the parent fluids of the neutral-pH reservoir which is around 310°C. The deep parent fluids are possibly composed of liquid-phase. However, the wells having high temperatures and lying near MG-3D, the representative of parent fluids, are composed of two-phase fluids with calculated vapour *gain* of around 0.5-5.0%. Moreover, these wells have higher gas contents than the other wells in the south. The vapour gain is interpreted to be caused by the development of upper steam-rich horizon induced by drawdown during well discharges, as in the case of well MG-3D (Bolanos, 1996), and by the presence of a natural two-phase zone above the parent liquid reservoir. *On* the other hand, the wells in the outflow zone in the south showed vapour losses of up to 7.0% which *can* be due to the effects of cooling and degassing processes.

Well MG-4D, a well whch has a cooler fluid inflow, have gained vapour of abut 1.0%. Moreover, the SO_4 and gas contents of the well are higher than the other hotter wells in the east. It is therefore possible that the inflowing cooler fluids in the well may not be cold meteoric waters but steam condensates which contains abundant non-condensable gases. Above the well track of MG-4D is the Paril fumarole whch indicated reservoir temperature of 280°C. In the case of MG-10D, a peripheral well with very poor permeability, the vapour gain of around 1.0% is interpreted to be caused by steam enrichment due to "drying-up" of the well.

4.3 Tongonan Field

Tongonan field was described as a fully-equilibrated hydrothermal system based on its mineral and fluid equilibria (PNOC-EDC, 1993; Salonga et al., 1996). The center of the reservoir is marked in the surface by the Kapakuhan fumarole whch indicated a temperature of 320°C. This temperature is encountered by the wells in Upper Mahiao, thus it is concluded that the gases in Kapakuhan fumarole are products of the first boiling of the deeper fluids in Upper Mahiao. Towards the outflow sector in the south, that is in South Sambaloran and Malitbog sectors, there is a decline in fluid temperature as well as losses in the original vapour by 2.0 to 5.0%. The Bao fumarole which marks the outflow sector of Tongonan in the surface appears to have been derived from the outflowing fluids at boiling temperature of around 180°C. In the north of Upper Mahiao, well 411D indicated inflow of cooler fluids which is composed of liquid-phase. These cooler fluids are also reflected on the chemistry of the neighboring wells 416D and 417D.

The commercial operations of Tongonan-1 power plant have brought about changes in Tongonan reservoir. One of the changes is the vapour gain in the wells at Mahiao sector by as much as 5.0% because of development of shallow steam cap induced by the drawdown of deep liquid reservoir. On the other hand, the production wells in both Mahiao and Sambaloran sectors lying proximate to the reinjection sink exhibit vapour loss by as much as 2.0-5.0%. This is explained by encroachment of degassed reinjected fluids into the production wells.

5.0 CONCLUSIONS

Gas equilibria indicated vapour gain in the fluids of Alto Peak geothermal field attesting to the high-gas contents of the thermal fluids. Moreover, the Danglog solfatara can be associated with parent fluids having temperature of above 370°C. These altogether reflect the presence of a magmatic system which is still evolving into a hydrothermal system beneath Alto Peak.

In Mahanagdong, the thermal fluids in the vicinity of the upflow zone have gained about 5.0% vapour owing to the pressure drawdown and boiling of the deep thermal fluids. The fluids in the outflow zone towards the south have lost about 7.0% of the original vapour. The acid wells in the north can be compared to Alto Peak fluids in which the original magmatic gases have not still attained full equilibration with the reservoir rocks.

In Tongonan, the upflow zone in Upper Mahiao hosts a natural shallow two-phase zone which have gained 1.0% vapour due to pressure drawdown and aquifer boiling. The outflowing fluids towards Sambaloran and Malitbog have lost 1.0% of the original vapour.

The commercial operations of Tongonan-1 induced pressure drawdown in Mahiao sector whch has shown vapour gain of up to 1.0%. On the other hand, the wells affected by influx of reinjected fluids have shown vapour loss by about 5.0%.

REFERENCES

Bolanos, GT, 1996. Geochemistry of the Medium-term Discharge of well MG-3D. PNOC-EDC internal report.

D'Amore, F., 1991. Applications of Geochemistry in Geothermal Reservoir Development. UNITAR/UNDP Publication, Rome, Italy.

D'Amore, F. and Celati C., 1983. Methodology for calculating steam quality in geothermal reservoirs. Geothermics, v. 12, no. 2/3, p. 129-140.

D'Amore and Truesdell, AH., 1985. Calculation of geothermal reservoir temperature and steam fractions from gas compositions. Geoth. Res. Coun. Trans., v. 9, p. 305-310.

D'Amore and Truesdell, AH., 1988. A review of equilibrium constants of gaseous species of geothermal interest. Sci. Geol. Bull. v.41, 0. 309-332.

D'Amore, F., Ramos-Candelaria, MN., Seastres, J.S., Ruaya, J.R. and Nuti, S., 1993. Application of gas chemistry in evaluating physical processes in the southern Negros (Palinpinon) geothermal field, Philippines. Geothermics, v. 22, no. 5/6, pp. 535-553.

Giggenbach, W.F., 1980. Geothermal gas equilibria. Geochim. et Cosmochi. Acta, v. 44, p. 2021-2032.

Parrilla, E.V., Jordan, O.T. and Ruaya, J.R., 1995. Mahanagdong field geochemistry resource assessment update. PNOC-EDC internal report.

PNOC-EDC, 1993. Greater Tongonan geothermal field, integrated resource assessment. PNOC-EDC internal report.

Salonga, N.D., 1996. The geochemistry of the thermal fluids in Alto peak magmatic-hydrothermal system, Leyte, Philippines, PNOC-EDC internal report.

Salonga, N.D., Auman, RO, Alincastre, R.S., Siega, F.L., Pa-a, J.E. and Bolanos, G.T., 1996. Baseline chemistry of Tongonan geothermal field prior to Leyte-Cebu and Leyte-Luzon interconnections, PNOC-EDC internal report.

Takashima, I, Delfin, F.G., and Santos, F.R., 1996. Chronology of volcanics and hyrothermal events in the Alto Peak geothermal field based on thermoluminescence dating. PNOC-EDC Geothermal Conference Proceedings, Manila.

Appendix 1:
Gas Data in Tongonan, Mahanagdong and Alto Peak

1. Fumaroles and Seepages

Fum. Name	Date	Meas. Temp.	CO_2	H_2S	NH_3	N_2	H_2	CH_4	Ar
			mmoles						
Kapakuhan	12/14/95	95	1314	58.60	n.a.	8.056	8.048	3.759	0.093
Bao	12/21/95	187	42	0.87	n.a.	0.990	0.014	0.027	0.006
Banat-i	12/21/95	166	63	1.52	n.a.	1.333	0.021	0.029	0.042
Mahanagdong	11/29/94	98	9591	59.39	n.a.	20.653	4.786	17.871	0.052
Paril	11/28/94	94	4986	59.39	n.a.	20.728	6.788	12.650	0.156
Danglog	1/14/90	94	388	34.00	n.a.	1.540	10.200	5.420	0.005
Tapol	1/15/90	52	419	0.54	n.a.	2.830	0.001	1.070	0.033

2. Alto Peak Geothermal Field

Well Name	Date	T(Quartz) °C	CO_2	H_2S	NH_3	N_2	H_2	CH_4	Ar
			mmoles/100 moles in total discharge						
AP-1D	12/20/92	242	5215	87.10	15.34	131.48	125.26	208.22	1.474
AP-2D	5/4/93	315	1539	39.29	10.62	4.137	21.723	59.000	3.620
AP-4D	12/20/92	247	508	2.22	1.100	5.155	0.680	10.305	0.047
AP-5D	1/7/93	233	609	4.00	1.932	4.598	6.790	27.517	5.280
AP-7D	1/6/95	247	816	117.44	0.008	2.082	4.335	0.693	0.008
AP-8D	5/11/95	224	993	24.20	7.510	1.411	1.386	403.90	0.008

3. Mahanagdong Geothermal Field

Well Name	Date	T(Quartz) °C	CO_2	H_2S	NH_3	N_2	H_2	CH_4	Ar
			mmoles/100 moles in total discharge						
MG-1	6/1/81	270	225	1.65	0.000	0.000	0.000	0.000	n.a.
MG-2D	11/14/81	266	100	0.98	0.245	0.000	0.000	0.000	n.a.
MG-3D	9/16/92	290	1133	24.69	4.054	5.440	1.347	0.599	n.a.
MG-4D	11/26/90	193	123	0.57	0.288	5.048	0.103	0.613	n.a.
MG-5D	8/19/83	272	1728	4.10	0.912	5.554	0.467	6.145	n.a.
MG-7D	1/10/91	274	177	3.24	0.442	1.061	0.120	0.874	n.a.
MG-9D	4/26/94	280	123	7.49	0.015	3.903	0.025	0.200	0.031
MG-10D	3/9/94	226	5868	21.29	9.913	0.475	0.018	16.565	n.a.
MG-13D	10/31/94	290	199	6.31	0.941	0.307	0.000	0.293	n.a.
MG-14D	8/16/94	294	749	11.68	4.010	0.188	1.100	0.902	n.a.
MG-15D	12/17/94	270	257	9.93	0.049	2.051	0.362	1.249	n.a.
MG-16D	9/2/96	271	129	2.52	0.356	0.927	0.055	0.116	0.012
MG-17D	11/23/94	240	128	1.65	0.241	0.732	0.009	0.308	n.a.
MG-18D	1/17/95	271	296	2.91	0.578	0.506	0.027	0.384	n.a.
MG-19	1/2/95	275	215	4.37	1.158	0.879	0.033	0.365	n.a.
MG-20D	1/24/96	250	206	10.42	0.018	5.044	1.310	1.139	0.075
MG-21D	10/17/95	275	321	41.29	0.107	23.101	1.823	1.057	0.312
MG-22D	8/12/96	260	136	3.98	0.460	0.821	0.043	0.299	0.018
MG-23D	6/24/96	260	196	3.36	0.684	1.317	0.335	0.347	0.021
MG-24D	7/19/96	260	1983	10.56	2.579	1.325	1.830	22.929	0.012

4. Tongonan Geothermal Field

Well Name	Date	T(Q) °C	CO_2	H_2S	NH_3	N_2	H_2	CH_4	Ar
			mmoles/100 moles in total discharge						
101	03/08/96	270	119	7.25	0.436	0.640	0.653	0.367	0.010
102	02/08/96	272	198	13.13	0.716	0.326	1.064	1.699	0.006
103	02/07/96	276	84	11.14	0.542	0.736	0.058	2.103	0.018
105D	02/01/96	266	16	2.12	0.214	0.003	0.008	0.005	0.001
106	01/06/96	281	163	13.10	0.662	0.378	0.806	0.423	0.008
108	02/01/96	266	441	20.09	0.830	0.926	2.716	0.609	0.012
110D	02/09/96	305	182	18.89	0.691	0.262	1.901	0.339	0.006
202	03/16/95	275	69	2.41	0.321	0.054	0.020	0.022	0.000
209A	03/06/96	295	177	13.69	0.471	0.329	0.770	0.269	0.006
212	03/04/96	286	84	6.14	0.480	0.239	0.256	0.136	0.004
213	03/06/96	292	61	4.15	0.295	0.188	0.110	0.113	0.005
214	03/02/96	274	154	6.76	0.525	0.475	0.105	0.213	0.007
215	03/04/96	273	120	6.77	0.546	0.488	0.595	0.226	0.007
301D	09/01/83	275	18	0.72	0.169	2.197	0.011	0.014	n.a.
302	09/08/95	273	73	5.94	0.336	0.472	0.039	0.103	n.a.
304D	02/14/95	271	159	5.88	0.526	0.544	0.314	0.299	n.a.
306D	05/20/95	262	38	5.46	0.354	0.172	0.046	0.035	n.a.
408	04/19/82	270	473	6.08	0.898	1.740	0.653	1.536	n.a.
409	05/27/82	284	243	7.01	0.701	14.877	0.941	0.494	n.a.
410	12/2/95	310	120	8.07	0.463	5.377	1.215	0.381	0.090
411D	09/03/84	256	47	0.52	0.205	0.307	0.045	0.202	n.a.
412D	03/17/95	300	245	24.05	1.137	1.006	2.097	0.183	n.a.
413D	04/10/95	292	123	10.55	0.392	0.042	0.144	0.033	n.a.
414D	03/27/95	270	134	10.42	0.679	1.317	0.467	0.138	n.a.
415D	04/17/95	284	304	15.22	0.673	0.296	1.111	0.287	n.a.
416D	07/31/95	247	298	7.90	0.599	0.805	1.106	0.731	n.a.
417D	11/20/95	265	250	7.19	0.821	0.620	0.595	0.449	n.a.
418D	11/08/95	273	108	7.35	0.360	0.691	0.945	0.180	n.a.
501	10/25/85	288	23	3.45	0.159	0.111	0.024	0.228	n.a.
508D	03/10/82	267	77	1.74	0.395	8.541	0.110	0.730	n.a.
509	02/07/84	256	81	1.68	0.003	2.510	0.035	0.095	n.a.
510D	03/08/82	268	72	2.80	0.321	0.633	0.053	0.277	n.a.
511D	03/24/82	277	389	6.27	0.461	2.820	0.310	2.900	n.a.
513D	02/03/84	269	19	0.50	0.194	0.074	0.020	0.059	n.a.
514D	01/10/83	285	41	1.24	0.218	0.538	0.041	0.130	n.a.
515D	09/24/82	291	139	3.07	0.425	25.780	0.235	1.663	n.a.
516D	06/26/84	299	102	3.35	0.275	0.326	0.152	0.278	n.a.

Notes:

1. *n.a. means data not available*
2. *the temperatures in Bao and Banat-i fumaroles are based on T(Quartz)*