STABLE ISOTOPE GEOCHEMISTRY OF THE TONGONAN GEOTHERMAL SYSTEM
LEYTE, PHILIPPINES

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ABSTRACT

Stable isotope and geochemical data on samples from natural features, shallow wells and deep wells collected over a number of years from the Tongonan area of Leyte have been evaluated. The variations in the isotopic compositions of the thermal waters are used to describe natural processes occuring within the system. The effect of the "excess enthalpy" of the deep wells on the isotope data is formulated. Water from the deep Tongonan wells shows an oxygen-18 shift of $5^{o}/oo$,which is larger than at Wairakei and Broadlands, probably in part became of the high temperatures at Tongonan, Recent measurements indicate that the deuterium shift is very much smaller than previously thought. Isotopic measurements of methane in the gases suggests differing flows from the Eastern and Central Philippine faults.

INTRODUCTION

Isotopic measurements of the geothermal fluids and local groundwaters of the Tongonan area have been made since 1973 when exploration commenced. The results have been discussed by Glover (1976), Barnett (1979) and Camales (1980) at various stages of the development of the field. This paper aims to discuss the result in terms of the hydrogeochemical model proposed by Lovelock, Cope and Baltasar (1982). (For convenience we will refer to their paper as LCB throughout this present paper). In particular we will deal with isotopic aspects of the special features of this field particularly that of excess enthalpy and the much larger range of mineralisation compared to that found in fields such as Wairakei. In addition gas isotopic measurements which have been made from a limited number of fumaroles and wells are discussed below.

COLLECTION, MEASUREMENT & CALCULATION

Figure 1 shows the general location of the Tongonan field in relation to the coast of Leyte. The location of samples collected in the search for the source of the geothermal water are shown in this figure. For details of the well locations and the geology of the area the reader is referred to the paper of LCB elsewhere in this volume.

Well water and steam samples have been collected either by using a downhole sampler or by separating steam and water phases of the wellhead using a twin cyclone webre separator. Gas samples have been collected from the steam phase into an evacuated flask containing CO_2-free sodium hydroxide and analysed according to the techniques of Lyon and Hulston (1982).

The water and steam samples have been analysed isotopically using the techniques and standardisation described by Hulston et al (1981). As a result the data for pre-1975 samples differ slightly from those given by Glover (1976). The total discharge (td) isotopic values have been obtained from the steam (s) and water (w) phases collected using the webre separator using the relationship

$$\delta_{td} = X\delta_s + (1-X)\delta_w \quad \ldots\ldots\ldots\ldots(1)$$

where δ refers to δD_{SMOW} or $\delta^{18}O_{SMOW}$ and X is the steam fraction at the separation temperature as calculated from the enthalpy of the well at the time of the collection and the saturated steam and water enthalpy at the separation temperature. In some cases the water phase has been collected from the weirbox (at ~100°C) rather than the webre separator, thus requiring a calculation technique which takes the differing temperatures of steam and water separation into account. We have chosen to m e equilibrium isotopic data to estimate the isotopic composition of the total discharge from the steam and water phases independently as follows:-

If $e_{ws} = 1000 \ln \alpha_{ws}$ represents the equilibrium fractionation factor between water and steam then to a first approximation

$$\delta_w = \delta_s + e_{ws} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

then the total discharge can be calculated from the steam phase using equation (1) as

$$\delta_{td} = X\delta_s + (1-X)(\delta_s + e_{ws})$$

$$= \delta_s + (1-X)e_{ws}$$

where X is the steam fraction calculated at the steam separation temperature.

Similarly using the water phase -

$$\delta_{td} = \delta_w - X'e_{ws}$$

TABLE 1 - **LOCAL METEORIC WATERS**

Name	Date ddmmyy	Temp °C	$\delta^{18}O$ ‰	‰
Mahiao River	200574	30	-6.14	-37.5
Matinao River	301075		-6.29	-38.5
Malitbog River	200574	30	-6.17	-38.5
Bao River	130574	30	-6.36	-38.7
Baneti St. nr TGE8	041175		-6.74	-41.7
U Paril Stream	130574	30	-6.9	-42.0
L Paril Stream	130574	30	-6.8	-42.0
L Imelda surface	150574	27.5	-5.68	-36.3
L Imelda 0.5m	150574	30	-5.56	-35.2
L Imelda outlet	150574	27	-5.43	-34.6
L Imelda outlet	070782	25	-5.84	-37.0
Taboyho St #1	100782	26	-7.36	-47.3
Libas St #2	100782		-5.77	-34.0
Alto Pk St #3	100782	24.5	-6.33	-36.1
Ormoc cold well	140782		-7.33	-48.0
Rain Mahiao	081080		-7.33	-44.5

where X' is the steam fraction calculated at the water separation temperature (100°C for weirbox).

The equilibrium fractionation factors were obtained using approximations of formulae obtained by Bottinga and Craig (1968)

$$\epsilon(^{18}O) = 0.766(10^{6}T^{-2}) + 1.21(10^{3}T^{-1}) - 7.5$$

$$\epsilon(D) = -54.4(10^{9}T^{-3}) + 372.8(10^{6}T^{-2}) - 808.1(10^{3}T^{-1}) + 560$$

Application of this procedure gives two estimates of δ_{td} which ideally should coincide. In all cases however it was found that this procedure over-estimated the difference between steam and water phases indicating that the steam-water separation process is occurring so fast that only 70–95% isotopic equilibrium was being attained. We have therefore adopted a procedure where we use $\epsilon = 0.9\epsilon_{\epsilon}$ in the above equations. This gives estimates of δ_{td} which normally agree within 0.2‰ in $\delta^{18}O$ and 1‰ in 6D. These two values of δ_{td} are then averaged using the webre steam fraction to give the values shown in Table 3.

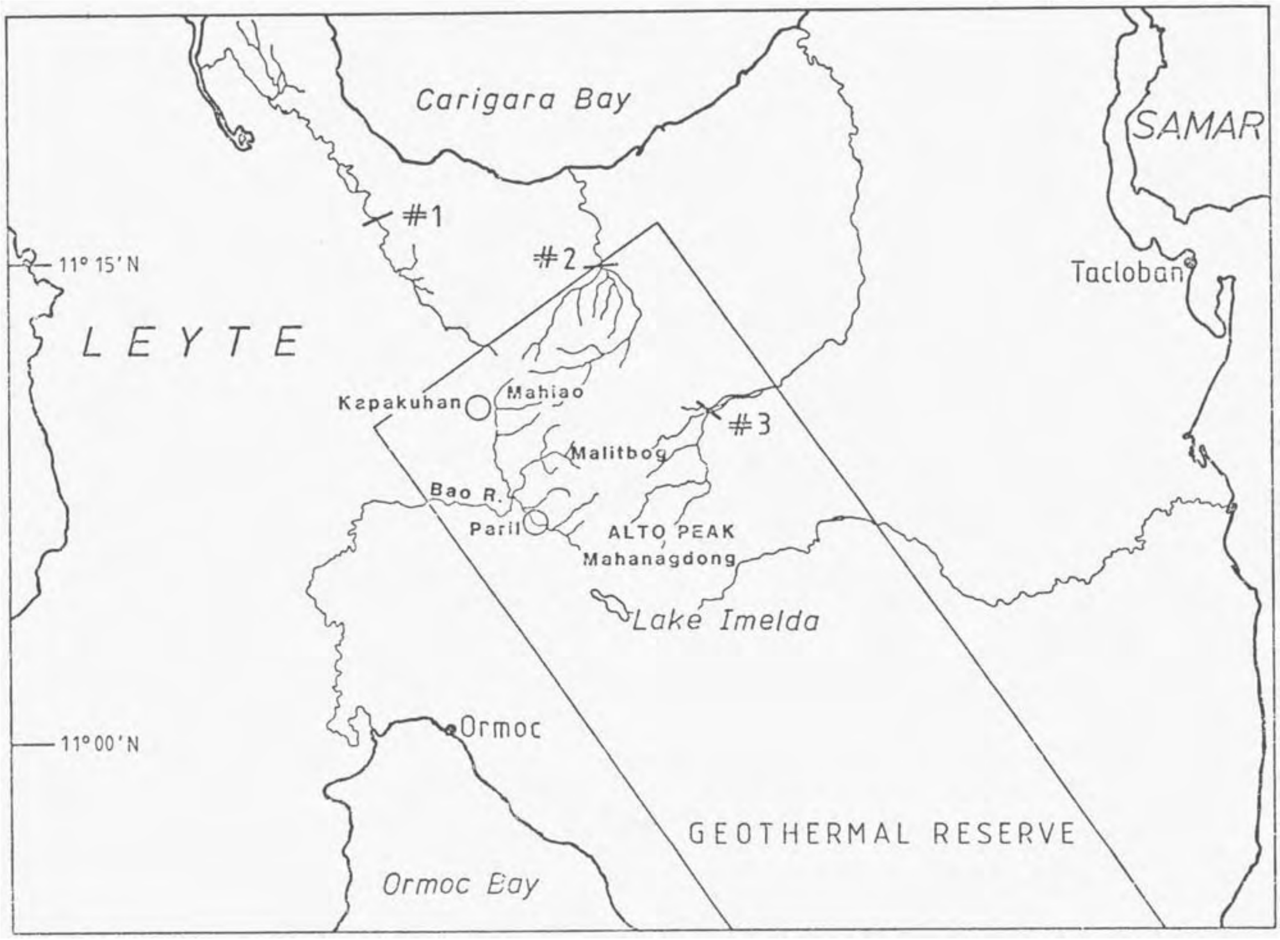

Figure 1 - Locality of Tonqonan Geothermal Field

TABLE 2 - EXPLORATION WELLS

Well	Date ddmmyy	Dep m.	SP MPag	Temp °C	Cl mg/kg	SiO_2	$\delta^{18}O$ ‰td	δD ‰td
TGE1	130574	0	AP	93.3	26	154	-6.3	-40.0
TGE2	200576	0	AP	71.7	11	72	-6.8	-42.6
TGE3	140574	244			11		-6.8	-43.6
TGE3	140574	442			195		-6.5	-42.0
TGE4	281075	149	0.95	183	3094	374	-2.23	-34.2
TGE5	020375	351		142	2832	192	-3.34	-30.3
TGE5	040375	0	AP	99?	3067	204	-2.90	-27.8
TGE5A	251075	174	1.60	189	2953	302	-2.65	-37.0
TGE6	040375	610		137	5.7	21	-6.2	-44.4
TGE7	010375	567		148	88	32	-6.80	-38.9
TGE8	041175	236	1.67	<40	17	15	-5.90	-40.8
TGE9	081175	244	0.82	45	41		-6.28	-37.9
TGE9	271175	244	0.82	45	41	27	-6.34	-39.6
TGE10	300776	582	4.21	249	1.8	275	-4.67	-29.4

RESULTS

Figure 2 shows a plot of 6D v $\delta^{18}O$ for the local waters, shallow wells and deep wells of the Tongonan area. The location of these wells are given by LBC but it should be emphasised that in most cases the isotopic samples were not taken under the conditions of minimum enthalpy selected by LBC and hence it has been necessary to include a brief summary of the chemistry in Table 3.

CORRECTIONS FOR EXCESS ENTHALPY

Where a well indicates excess enthalpy as described by LCB, correction of the isotopic values requires a knowledge of the depth from which the excess steam is entering the system. When the collection is made under conditions of high wellhead pressure, hydrostatic pressure considerations require that this excess steam has come from deep in the well. Using the principle that we should under-estimate the correction rather than over-estimate it we have chosen to assume that the excess steam has come from the hottest source of water in the well as indicated by the silica equilibrium temperature. The 6_{aq} values calculated using the excess calculated in Table 3 and equilibrium isotope data are indicated by the dotted arrows in figure 2. It is interesting to note that the 6_{aq} values for wells 401(273°C) and 407(297°C) are very close but differ from 410(313°C) by 3‰ in 6D. Other deep wells affected by the excess enthalpy correction are 103(278°C), 209A(290°C) and MG1(254°C) all of which have smaller oxygen-18 shifts.

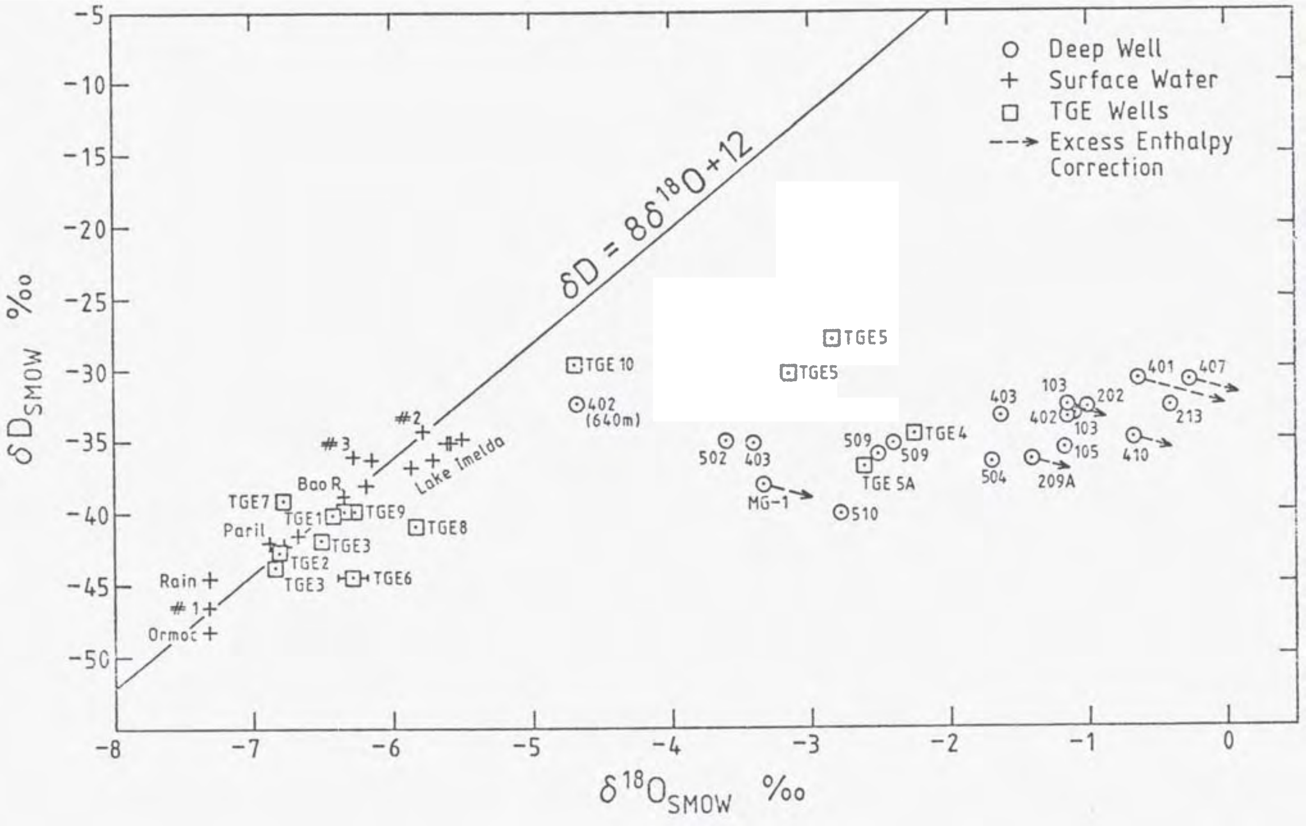

Figure 2 - Deuterium and oxygen isotopic composition of surface and well waters

TABLE 3 - DEEP WELLS

Well	Date ddmmyy	Depth metres	WHP MPag	H^o kJ/kg	Cl_{ap} mg/kg	$T(SiO_2)$ °C	Cl_{aq} mg/kg	Excess H kJ/kg	$\delta^{18}O_{td}$ o/oo	δD_{td} o/oo
103	230678	WEBR	1.00	1610	12261	278	7657	795	-1.14	-32.7
103	091181	1350					4445		-1.13	-33.5
105	300880	1000			12633	272	8275		-1.15	-35.7
202	240678	1829	1.66		12400	284	7722		-1.00	-32.7
209A	270880	WEBR	3.43	1000	13141	280	8058	560	-1.4	-36.4
213	070781	SEP		1320	13587	287	8376	40	4.6	-33.5
401	240678	WEBR	1.88	2000	14174	273	8625	795	-0.64	-30.2
402	250880	640					2005		-4.67	-32.3
402	250880	1600							-1.12	-33.3
403(fdd	200880	WBOX	0.18	960	4423	241	3346		-3.4	-34.6
403	260681	1890			5190		5190		-1.65	-33.2
407	240678	WEBR	1.08	1750	13905	297	8145	425	-0.26	-30.7
410	150981	WEBR	>4.4	1870	15685	313	8622	455	-0.7	-35.0
502	141181	1700			4363	267?	2836		-3.6	-35.0
504	200880	WBOX		1060	7696	241	5541		-1.7	-37.2
509	131081	WEBR	0.78	977	6015	246	4262		-2.4	-35.0
509	141281	WEBR	1.32	1065	5055	245	3605		-2.5	-36.0
510	24282	2300					4810		-2.8	-40.2
MG-1	051081	WEBR	2.61	1445	4023	254	2734	335	-3.3	-38.0

TABLE 4 - GAS ISOTOPE ANALYSES

Location	Sample Date	Surface Temp °C	$\delta^{13}C$(°/oo)		δD(°/oo)		Temperatures (°C)		
			CO_2	CH_4	CH_4	H_2	$\Delta^{13}C$ CO_2-CH_4	ΔD H_2-H_2O	ΔD CH_4-H_2O
407	240678		-2.2	-20.8	-141	-404	395	325	300
Kapakahon	120776		-2.2	-21.5	-138		381	440	
401	240678		-2.1	-23.3	-159	-453	345	265	160
Mahiao A	110776		-3.5	-27.8	-153		295	240	
TGElO			-1.1	-27.9		-434	265		292
103	230678		-3.5	-28.6	-147	-402	285	330	245
TGE5			-5.4	-27.7	-166		326	140	
Paril A	130776		-1.9	-25.7	-151	-491	303	230	226
Paril B	130776		-1.9	-26.2	-168	-474	2%	130	244

GAS ISOTOPES

The gas isotope results (Table 4) show results from fumaroles, exploratory wells and deep wells, ordered from North to South. It is useful to consider both the isotopic ratios (delta values) and the equilibrium isotopic temperatures. Isotopic temperatures from $\Delta^{13}C(CO_2-CH_4)$ equilibrium are believed to represent temperatures at considerable depth (Hulston, 1977, 1982), while the $\Delta D(H_2-H_2O)$ temperature has a faster equilibrium time and usually indicates temperatures at drillable depth. The equilibrium reaction mechanism between CH_4 and H_2O is still under investigation and the significance of the $\Delta D(CH_4-H_2O)$ temperature is not certain at this time. Usually (Truesdell and Hulston, 1980 and Lyon and Hulston, 1980) $\Delta D(CH_4-H_2)$ and $\Delta D(H_2-H_2O)$ temperatures are similar but the results in Table 4 suggest that $\Delta D(CH_4-H_2O)$ represents temperatures closer to the surface than those derived from $\Delta D(H_2-H_2O)$.

It will be seen from Table 4 that this ordering shows a general tendency for $\delta^{13}C(CH_4)$, $\delta D(CH_4)$ and $\delta D(H_2)$ to become more negative from north to south and for temperatures to be highest in the north. This change is not linear and in particular a sharp change in $\delta^{13}C(CH_4)$ occurs on either side of well 401 suggesting different sources of methane from the East and Central Philippine faults. Interestingly the $\delta^{13}C(CH_4)$ value of the Southern-most sample, Paril, is not as negative as other samples on the Central Philippine fault. It would be interesting to see if this isotopic value was similar to that of the Mahanagdong (MG) series of wells.

DISCUSSION

The δD v $\delta^{18}O$ plot in figure 2 indicates that the meteoric waters of Leyte show a range of isotopic variation similar in extent to that of Fiji (Cox and Hulston, 1980). The most negative deuterium values from Ormoc city (Aqua Dulce well) and Taboyho #1 would indicate a leeward effect, while the more positive delta values appearing in the north-east (#2 and #3) suggest this as the windward direction. The slightly lower value from Alto Peak stream #3 is presumably due to an altitude effect. The samples from Lake Imelda are also at the more positive end of the range but it is possible that isotopic enrichment may have occurred due to evaporation.

Figure 2 shows that a significant oxygen-18 shift occurs for the deep well samples but that the deuterium isotope value is similar to that of the eastern meteoric samples #2 and #3 in most cases. Some exploration (TGE) wells fall in this group while others (particularly the cool ones) are close to meteoric water line and a third group are enriched in deuterium with an oxygen-18 shift smaller than than of the deep wells. These deuterium enriched TGE wells are presumed to represent hot water from which steam has been lost by evaporation in the 150 to 200°C range.

The most interesting and puzzling feature of the deep well results is that for a given oxygen-18 shift there is a range of some 3-4°/oo in the deuterium concentration. In particular the deuterium results for wells 401 and 407 and 410 differ by 3°/oo and the former are enriched relative to local meteoric waters. This difference does not appear to be related to the major faults but it is significant that well 401 and 407 produce from above the diorite transition zone while 202 and 209A produce within it and 410 below it. However at present no mechanism for enrichment of deuterium at ~300°C without a corresponding depletion of oxygen-18 is known to the authors.

In an attempt to elucidate these isotopic water results further the oxygen isotope shift has been plotted against the chloride content of the deep aqueous in figure 3 and against the silica temperature in figure 4. The $Cl_{(aq)}$ v $\delta^{18}O$ plot suggests a general relation between these parameters with a considerable apparently unrelated scatter. The $T(SiO_2)$ v $\delta^{18}O$ plot while also showing a general relationship of increasing oxygen shift with increasing temperature also shows some well particularly 410 and 502 above the general trend and others - particularly 504 below the trend. The high temperature for well 410 presumably relates to production from a deeper zone than the other wells as noted above. The change in $T(SiO_2)$ from well 502 through well 509 to well 504 however reflects the change in location from the East Philippine fault to the Central Philippine fault and may suggest a difference in temperatures between fluids coming up these faults. This would relate to the suggested hydrological flow directions indicated in figure 8 of LCB.

CONCLUSIONS

From these isotope results it would appear that the source of the recharge water is most likely to be rainfall falling to the east of the Tongonan geothermal area.

The oxygen isotope shift of over 5°/oo is much greater than that found in fields like Wairakei and Broadlands but less than that found at Ngawha. In addition the mineralisation of the Upper Mahiao wells 401, 407 and 410 is much greater than in any of the New Zealand fields. There is a general correlation of mineralisation with the oxygen shift but the correlation with temperature is somewhat lower, suggesting that some other factor, possibly conductive heating or cooling, is also contributing

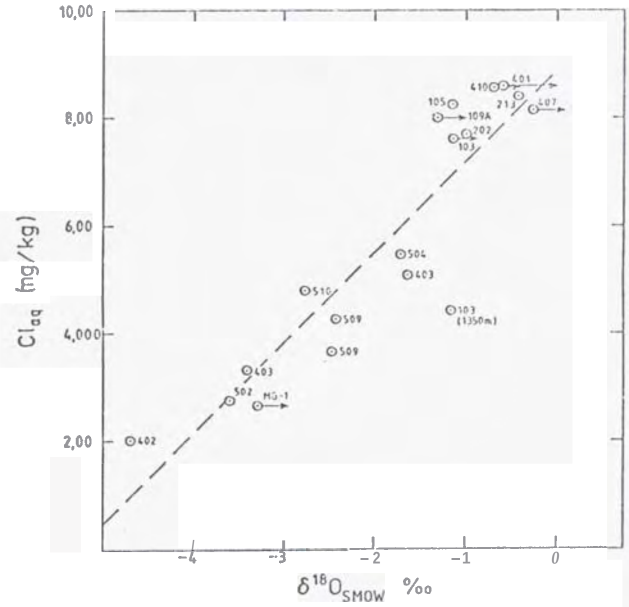

Figure 3 - Chloride content versus oxygen isotope composition for deep well waters

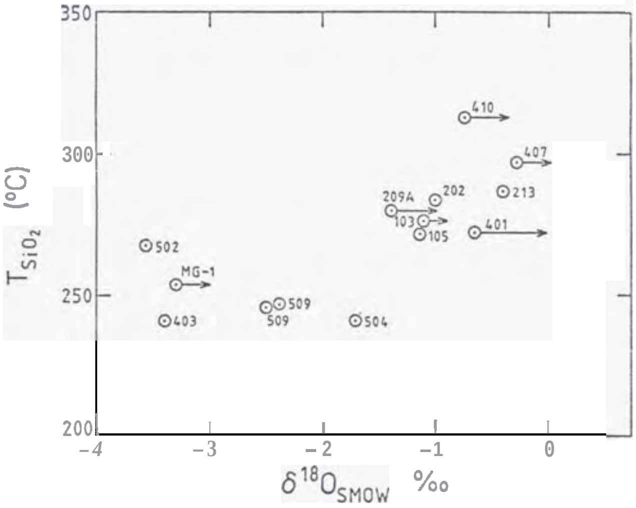

Figure 4 - Silica temperature versus oxygen isotope ratios for deep well waters

to the temperature. The lower chloride samples have lower oxygen isotope shift indicating either dilution or less interaction with a cooling magma plume at depth. Measurement of isotopic composition of gases in the discharges suggests a number of different upflows are occurring, probably along the Eastern and Central Philippine faults.

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