DETERMINATION OF THE NATURE OF ACIDIC FLUIDS IN THE PALINPINON GEOTHERMAL FIELD, PHILIPPINES THROUGH THE USE OF $\delta^{34}S$ IN SULFATES AND SULFIDES

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ABSTRACT

The analysis of the $\delta^{34}S$ isotopic compositions of the sulfates and sulfides dissolved in the present day geothermaljluids and gases of the Palinpinon Geothennal Field, Philippines reveal that a majority of the acidic wells in thefield display condtions of isoiopic disequilibirum as denoted byfiactionationfactors that are much smaller than the equilibrium values at the depositional temperatures. Based on evidences from other foreign geothermal fields, it is believed that this apparent non-equilibrium condition is caused by the partial oxidation of the geothermal brine along the shallow portions of the reservoir. Other evidences indicating that H_2S partial oxidation is the main source of acidity among Palinpinon wells include the wide variation in the $\delta^{34}S$ values in sulfate and the apparent genetic connection of these acid fluids with the Kaipohans of Cuernos de Negros based on current $\delta^{18}O$ and Deuterium data Near equilibrium depositional values in BLID, PN22D, PN20D and NJ6D are believed to be the result of the re-equilibration of these acidic fluids formed along shallow oxidation zones) as these percolate down to the deeper portions of the reservoir where prevalent conditions (i.e., high temperatures, low pH and high ΣS) favor the rapid re-equilibration of $\delta^{34}S$ of aqueous surfate with the sulfides in H_2S.

1.0 INTRODUCTION

Continuous steam production and current revisions in the reinjection strategy within the Palinpinon Geothermal Field have raised concerns on possible large scale incursion of acidic fluids into producing wells as a result of the increasing pressure drawdown across the field The Geoscientific staff of PNOC-EDC is currently exerting efforts to fully characterize these fluids so that this possible problem could be addressed to effectively when the need arises. So far, only two studies have been conducted to determine the origin of these acid fluids through the use of sulfur isotopes and both contain conflicting views. The first study conducted by Robinson in 1987 concluded that these acid waters are steam heated in nature that displayed various indications of re-equilibration with depth The second study done by Bayon in 1995 allegedly disproved this theory giving credence to the idea that the acid fluids are rather deep magmatic in nature. This study aims to provide a different approach in interpreting pest and recent sulfur isotope data to hopefully resolve the issue on whether these acid fluids are steam heated or deep magmatic in nature.

Far this paper: all interpretations were based on the isotopic data gathered by Bayon in 19% and by Rae in 1997. Oxygen and hydrogen isotope data were taken from the work of Candelaria in 1992. Details on the analytical procedures are given elsewhere (e.g., Hulston and Shilton, 1958; Robinson and Sheppard, 1986 Ohmoto and Rye, 1979) and are not included in this paper. All isotopic data were taka fiom production wells with acidic components in their discharge chemistries and also from the various thermal and non-thermal (e.g. Kaipohan) surface manifestations within the geothermal field.

1.1 FIELD BACKGROUND

The Palinpinon Geothermal Field (a.k.a. Southern Negros Geothermal Field) is wholly owned and operated by the Philippine National Oil Company's Energy Development Corporation and it is presently supplying steam to electrical power plants operated by the government's National Power Corporation. These power plants are providing electricity to the entire island of Negros and to the adjacent islands of Panay and Cebu.

The Palinpinon geothermal field is situated at the southeastern portion of the island of Negros that lies approximately 500 aerial kilometers south of Manila. The production field is located along the headwaters of the Okoy River system located along the northwestern flank of Mt. Cuernos de Negros, a dormant, andesitic Quaternary volcano (Figure 1).

There are two production sectors within this geothermal field. The Palinpinon 1 sector lies within the sitio of Puhagan and houses a 112.5 MWe power plant; and the Palinpinon 2 sector which encompasses the sitios of Balasbalas, Nasuji and Sogongon, and which possesses three modular power plants with an installed capacity totaling 80 MWe. The entire field currently utilizes a complement of 47 production wells and 25 reinjection wells for the operation of both sectors.

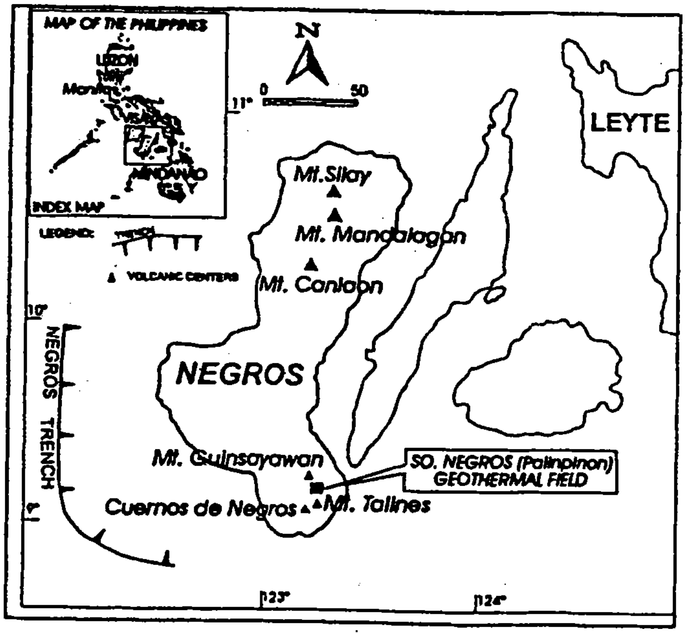

Fig. 1. Location map of the Palinpinon Geothermal Field, Philippines.

The geothermal reservoir is basically a water-dominated system situated along an elevated andesitic terrane. The hydrothermal system is related to the last volcanic activity of Mt. Cuernos de Negros that occurred approximately 14,000 years ago based on the ^{14}C dating of charred wood fragments recovered from young pyroclastic units. Details on the surface and subsurface geology of the area have been discussed extensively by several authors (Reyes and Tolentino, 1981; Seastres, 1982, Bogie and Leach, 1982, PNOC-EDC, 1988, Villarosa and Dulce, 1997). Publications on the geochemistry of the area include works by Harper and Jordan (1985), Gerardo et al (1993), D'Amore et al (1993), Seastres et al (1995), Hermoso et al (1996) and Robinson et al (1987). Permeability within the field is attributed mainly to fracturing associated to several NNE-NNW trending, steeply dipping normal and strike-slip faults that extensively crisscross the area. Around 95% of the field's production are derived from the intersection of these highly permeable faults (minor production comes from the intersection of lithologic contacts and pervious volcaniclastics).

2.0 RESULTS AND DISCUSSIONS

The fluid and gas sulfur isotope data for dissolved sulfide and sulfate, as expressed in per mil relative to the Canyon Diablo Troilite Standard, are presented in Tables I and II. The former contains data collected by Bayon in 1996 and the latter includes the set of data that were analyzed by Rae in 1997.

Table I Palinpinon Fluid and Gas Sulfur Isotope Data Collected by Bayon (1996)

Location	$\delta^{34}S\ SO_4$ (‰)	$\delta^{34}S\ H_2S$ (‰)	$\Delta SO_4\text{-}H_2S$ (‰)	T (°C)^A
PN13D	8.8	0*	8.8	236
	21.5	0*	21..5	236
	17.4	0*	17.4	236
	18.9	0*	18.9	236
PN18D	8.1	0*	8.1	258
	17.8	0*	17.8	258
PN20D	22.4	0*	22.4	256
	24.1	0*	24.1	256
PN22D	21.6	0*	21.6	292

Table I (cont.)

Location	$\delta^{34}S$ SO_4 (‰)	$\delta^{34}S$ H_2S (‰)	ΔSO_4-H_2S (‰)	T (°C)[A]
	21.5	0*	21.5	292
	18.2	0*	18.2	292
	21.6	0*	21.6	292
NJ5D	10.8	0*	10.8	270
	14.3	0*	14.3	270
	17.8	0*	17.8	270
NJ6D	14.6	-3.2	17.8	267
	18.0	0*	18.0	267
BL1D	20.0	0*	20	309
	23.0	0*	23.0	309
OK9D	16.3	0.4	15.9	283
	20.9	0*	20.9	283
	17.1	0*	17.1	283
OK10D	20.6	-0.24	21.02	252
	20.6	-0.5	21.10	252
	17.7	0*	17.7	252
Kaipohan	-3.1	0*	-3.1	21[B]
Mag-aso	0.0	0*	0	100[B]

* Data sets without any sulfur isotopes values in H_2S were given a default figure of 0‰ since isotope signatures for geothermal gases of magmatic nature approximate this value (Ohmoto and Rye, 1979).

[A] Temperature values based on actual downhole measurements (KT surveys) taken last 1995-1996 for corresponding wells.

[B] Orifice temperature (geothermometers are inapplicable due to steam heated nature of thermal manifestation).

Table II Updated Palinpinon Fluid and Gas Sulfur Isotope Data Analyzed by Rae (1997)

Location	$\delta^{34}S$ SO_4 (‰)	$\delta^{34}S$ H_2S (‰)	ΔSO_4-H_2S (‰)	T (°C)[A]
OK7 Downhole Sample (retrieved at 1650 m)	10.7	0*	10.7	199
OK10D	15.0	-1.960	16.96	252
PN13D	15.9	0*	15.9	260
PN18D	15.8	0*	15.8	256
PN20D	22.1	0*	22.1	256
PN22D	18.7	-0.12	18.82	292
BL1D	22.4	-0.630	23.03	252
NJ4D Downhole Sample (retrieved at 2500 mMD)	11.6	0*	11.6	273
NJ6D	16.8	-6.14	22.94	272
Pulangbato Warm Spring	2.1	0*	2.1	50[B]
Kaipohan Daku	-1.5	0*	-1.5	21[B]
Lagunao Warm Spring	15.7	0*	15.7	50[B]
Malaunay Warm Spring	16.6	0*	16.6	50[B]
Mag-aso Mud Pool/Solfatara	0.7	0*	0.7	100[B]
Palinpinon Hot Spring	6.9	0*	6.9	180[C]

* Data sets Without any sulfur isotopes value in H2S were given a mandatory value of 0% since isotope signatures for geothermal gases of magmatic nature approximate this value.

[A] Temperature values based on actual downhole measurements (KT surveys) taken last 1997 for corresponding wells

[B] Measured orifice temperature (geothermometers are inapplicable due to steam heated nature of thermal manifestation).

[C] Based on Na-K-Ca geothermometer estimates.

Isotopic values gathered in 1995 exhibit $\delta^{34}S$ in sulfate from +8.8‰ to +23‰ with an average of +18.04‰, while 1997 values did not vary much with the obtained range of –1.5% to +23‰ and a corresponding average of +13.22‰. The relevance of the wide variability in the $\delta^{34}S$ in sulfate dissolved in the liquid phase will be discussed later on. Values for $\delta^{34}S$ in H_2S in the gaseous phase for 1995 ranged from –3.2‰ to +0.4‰ while those derived for 1997 ranged from –6.14‰ to –0.63‰.. These values invariably approximate 0 ‰ and are believed to represent the magmatic origin for this gas specie (Ohmoto and Rye. 1979). The obtained values for $\delta^{34}S$ in H_2S in the Palinpinon Geothermal Field varies minimally from those obtained from other Philippine geothermal fields. This indicates that the $\delta^{34}S$ in H_2S from magmatic fluids of island arc melts, at least in the Philippines, is slightly depleted in $\delta^{34}S$ compared to mantle derived melts; and that the H_2S in geothermal well discharges is directly derived from the magma (Bayon, 1996).

2.1 ISOTOPIC DETERMINATION OF ACID FLUID NATURE

In disagreement with the theory expressed by Bayon in his 19% paper, the authors still assert that there are overwhelming isotopic evidences that will support the theory about the steam heated nature of the acidic fluids in Palinpinon. These evidences are discussed in the proceeding sections.

2.1.1 WIDE VARIATION OF $\delta^{34}S$ IN SULFATES

As stated in section 2.1 of this paper, the $\delta^{34}S$ values of sulfates dissolved in the fluid from Palinpinon's acidic wells range from a low of –1.5% to a high of +23‰ as seen in the 1995 and 1997 set of data. Bayon's main argument against the theory on the shallow generation of acidic fluids in Palinpinon was that the $\delta^{34}S$ of dissolved sulfate should be close to that of the isotopic signature of the oxidized sulfide (i.e., 0‰) because of its slow equilibration at low temperature (Bayon, 1996). According to this line of reasoning. acidic fluids produced from the oxidation of H_2S should produce isotopic signatures in sulfate equal to 0‰ with an allowance off 5‰ (Ohmoto and Rye, 1979). And since none of the wells in Palinpinon showed isotopic values within this specific range, it was outright concluded that the acid fluids encountered by the various boreholes in this field are not shallow in nature but rather deep and magmatic in origin

The aforementioned principle cited by Bayon was based on early studies conducted by authors like C.W. Field on ore minerals, mine waters and hotsprings wherein it was concluded that supergene sulfates should show a relationship of $^{34}S(\text{sulfate}) \approx {}^{34}S(\text{sulfide})$ as opposed to hypogene sulfates that typically show a $^{34}S(\text{sulfate}) \gg {}^{34}S(\text{sulfide})$ relationship (Field, 1966). However, recent developments in the interpretation of sulfur isotope data (especially when applied in geothermal systems), show that the ideal approach in interpreting this type of data is not as simple as this.

Later studies show that that the kinetic isotopic effects during the oxidation of fluids play an important role in the variation of $\delta^{34}S$ values of hypogene sulfate minerals as shown by Ohmoto and Rye in 1979. Ohmoto and Lasaga in 1982, Sakai in 1983 and Serrano et al in 1996. These authors demonstrated that kinetic effects control the isotopic composition of a sulfur compound produced by the oxidation of another sulfur compound. The molecules containing the lightest isotopes will act faster than molecules containing the heavier isotopes thereby enriching the reaction products with light isotopes in the case of a simple chemical system. The oxidation of sulfides to sulfates can be represented by the following reactions:

$$H_2{}^{32}S \xrightarrow{K1} {}^{32}SO_4^{2-}$$

$$H_2{}^{34}S \xrightarrow{K2} {}^{34}SO_4^{2-}$$

The ratio behveen the equilibrium constants of the above reactions (K1/K2) is called the isotopic kinetic effect. For example, if the value of this ratio is 1.005 (Nakai and Jensen, 1964), this implies that the $H_2\,{}^{32}S$ species will undergo transformation 5 per mil faster than the $H_2{}^{34}S$ species. Therefore, the resulting sulfate will have a ^{34}S deficiency of 5 ‰ with respect to that of the residual H_2S. It is important to mention that the K1/K2 ratio is also considered as the instantaneous enrichment factor regardless of the number of steps actually involved in the reactions and does not necessarily imply single step reactions (Ohmoto and Rye, 1979).

Figure 2 shows the isotopic variations of the sulfur compounds (H_2S and SO_4) as a function of the degree of oxidation obtained by a hydrothermal fluid. Ohmoto and Rye (1979) considered a fluid with the following initial characteristics: t = 250°C, initial isotopic and chemical equilibrium behveen sulfates and sulfides with $\delta^{34}S$ values of 25‰ and 0‰ respectively. Therefore, the value of the isotopic fractionation factor for both species at 250°C is 25‰. *If H_2S is partially oxidized to SO_4, $\delta^{34}S$ in H_2S will approximate 0‰ whereas the $\delta^{34}S$ in SO_4 will show as spread of values ranging from 25‰ to 0‰ depending on the degree of oxidation of the initial fluid Thus, the wider the variation of the $\delta^{34}S$ in sulfates (as in the case of Palinpinon), the stronger the argument that the sulfates were formed through the oxidation of H_2S.* This approach was also used in determining the cause of the wide variations in $\delta^{34}S$ of SO_4 within the Los Humeros geothermal field (Serrano et al, 1996).

The wide range of values for $\delta^{34}S$ of SO_4 in Tables I and II would indicate that the deep reservoir fluids were eventually mixed by shallow, steam heated fluids that percolated down to the lower reaches of the geothermal system. Based on Figure 6, one could assume that the lesser the value of your $\delta^{34}S$ of SO_4 , the grater was the degree of oxidation and that the oxidation process occurred much shallower within the reservoir. This assumption is based on the fact that the solubility of oxygen declines significantly with increasing temperature (Leach and Bogie, 1982). Furthermore, partial oxidation of H_2S within the deeper portions of hydrothermal systems is unlikely since oxidizing agents (e.g., oxygen) are not readily available particularly in the temperature range of 200 to 400°C (Ohmoto and Lasaga, 1982). Higher multifeed characteristics of the Palinpinon wells could explain the variations within a single borehole (see Tables 1 and 2).

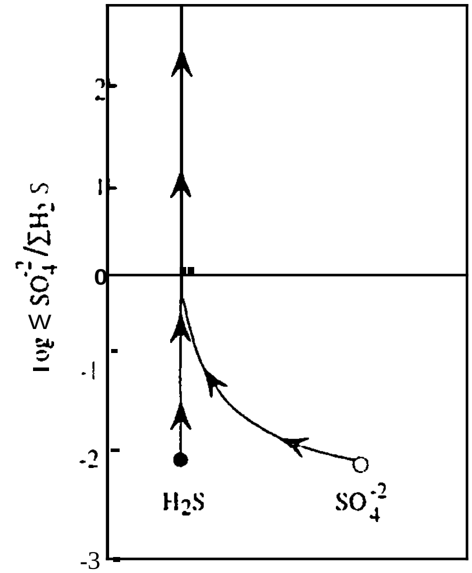

Fig. 2. Isotopic relations between coexisting sulfates and sulfide species for non-equilibrium oxidation conditions (after Ohmoto and Rye, 1979).

Sites of active acid fluid generation are believed to be generally confined within perched groundwater aquifers where geothermal gases and steam react with percolating groundwater to form sulfuric acid This can then react with the country rock to form sulfate rich fluid with a higher degree of mineralization. When this water trickles downward it can penetrate into, and mix with, the geothermal reservoir fluids because of its lower temperature and higher density (Bogie et al, 1987). Fluids of this character react with the country rock and form acid sulfate alteration zones that are characterized by the presence of kaolinite ± pyrophyllite ± alunite ± natroalunite ± diaspore ± anhydrite. Based on the petrographic analyses of inclusive well drillcuttings and core samples, these acid alteration zones are located from + 500 m AMSL in Puhagan to as low as - 1500 mAMSL within the Nasuji - Sogongon sector (Seastres, 1982, Bogie and Leach, 1982; PNOC-EDC, 1988). The elevation of the aforementioned perched groundwater aquifers may be controlled by stratigraphic or structural variations in permeability, or by the geothermal system itself when the liquid piezometric surface of the geothermal reservoir is some depth below the ground surface. In Philippine systems this depth can be of the order of 500 mAMSL (Bogie et al, 1987).

The explanation for the presence of high $\delta^{34}S$ of SO_4 in wells like BL1D, PN20D and PN22D will be explained in the following section

2.1.2 DEPOSITIONAL FRACTIONATION FACTORS < THEORETICAL FRACTIONATION FACTORS

Another evidence for the widespread occurrence of H_2S oxidation within the Palinpinon geothermal reservoir is the observed disequilibrium between the depositional (i.e., actual) and theoretical sulfate-sulfide isotopic fractionation factors in *almost* all **of** the samples analyzed for *sulfur* isotopes. Several authors (Ohmoto and Rye, 1979, *Ohmoto* and **Lasaga, 1982)** have noted **that** at temperatures below 350°C **almost** all the sulfate-sulfide mineral and **aqueous pairs** were formed from solutions in which the fractionation factors between aqueous sulfates and sulfides *(a")*were much smaller **than** the equilibrium values at **the** depositional temperatures *(a')* – see Figure 3. Based on the **studies** conducted by Ohmoto **and Lasaga** in 1982, the relationship $\alpha^m < \alpha^e$ in hydrothermal systems **were produced** primarily by the **partial** oxidation of H_2S. This **is because** the aqueous sulfates produced **by** the oxidation **of** H_2S would initially have $\delta^{34}S$ values similar to the $\delta^{34}S$ of H_2S and **the** addition **of** these sulfates *to* the original sulfates in solution would lower the ***a* values.** Such processes are believed to be responsible for **the** extremely low **1000** ln *a* values (i.e., less than 20) observed in many geothermal fluids, such **as** in the Wairakei, the Broadlands-Ohaki **and the** Ngawha systems (Figure 3). Magmatic acid fluids on the **other hand** owing *to* **their** highly mineralized, **high** temperature and **deep** seated nature, are expected *to* display isotopic equilibrium **with** respect *to* $\delta^{34}S$ to sulfate and **sulfides. This** assumption is **based** on the stable isotope chemistry **of** magmatic acidic fluids from a Mt. **Pinatubo** geothermal well (i.e., Pin-3D) that were found *to* be in isotopic equilibrium with andesitic magma and which eventually fell within the so-called "primary magmatic water" area espoused by Taylor in 1979 (Ruaya et al, 1991).

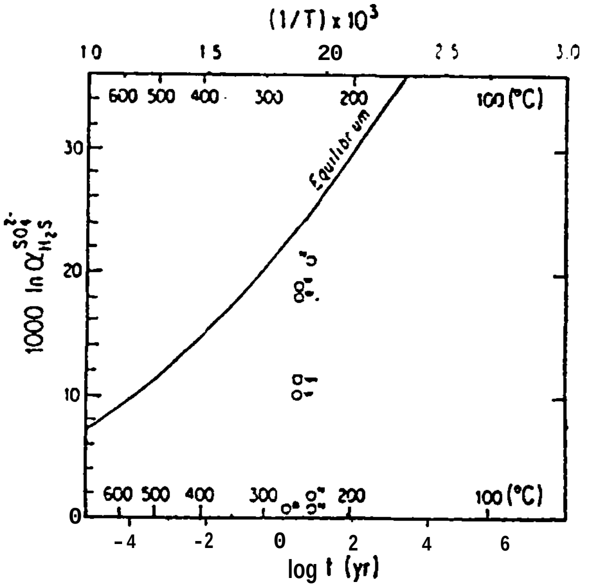

Fig. 3. Relationship between sulfate-sulfide isotopic fractionation factors and their temperatures for New Zealand Geothermal fields (after Ohmoto and Lasaga, 1382). Legend **used** : W=Wairakei, B=Broadlands, N= Ngawha.

Application of this approach for the Palinpinon samples is **shown** in Figures 4 and 5. **As** seen from **these figures,** majority **of** the acidic wells in Palinpinon possess the relationship referred to by Ohmoto and **Lasaga** (1982) **as** $\alpha^m < \alpha^e$ providing **the** strong evidence **that** the origin of **these** fluids stemmed from the **partial** oxidation of H_2S. Nevertheless, equilibrium and near equilibrium conditions were noted **in** a **small** number of wells such **as** PN20D, PN22D, **BLID** and NJ6D. However, it is believed that these are mere artifacts of re-equilibration rather than signatures of deep magmatic origin.

Studies conducted **by** Ohmoto and Rye (1978) **and Ohmoto** and **Lasaga** (1982) established **that** equilibration time between aqueous sulfates and sulfides is a function **of** pH, temperature and the overall sulfur concentration Table **III** shows **the** theoretical time *estimates* **required** for the attainment *of* 90 *percent* equilibrium **between** aqueous sulfates **and sulfides at** total sulfur content **(CS)**= 0.01 mole/kg H_2O.

Table III 90% Equilibration Time Estimates Between Aqueous Sulfates and Sulfides at $\Sigma S = 0.10$ **mole/kg** H_2O (after *Ohmoto* and Lasaga, 1982)

T (°C)	pH ≈ 2	pH ≈ 4 - 7	pH ≈ 9
350	**4.2** hrs.	17 days	10^2 yrs
300	15 hrs.	140 **days**	**Id yrs.**
250	**3 days**	**4.4 yrs.**	10^5 yrs.
200	**20** days	90 yrs.	**10' yrs.**
150	200 **days**	4×10^3 yrs.	10^9 yrs.
100	10 yrs.	4×10^5 yrs.	10^{12} yrs.
50	**5** $\times 10^2$ yrs.	2×10^8 **yrs**	10^{16} yrs.
25	5×10^3 **yrs.**	9×10^9 **yrs.**	10^{19} **yrs.**

N.B., If solutions contained 10^{-1} m (or 10^{-3}) of ΣS instead of 10^{-2} m, the time needed to attain the same degree of equilibrium would be decreased (or increased) by a factor of 10 from the t values shown in the table.

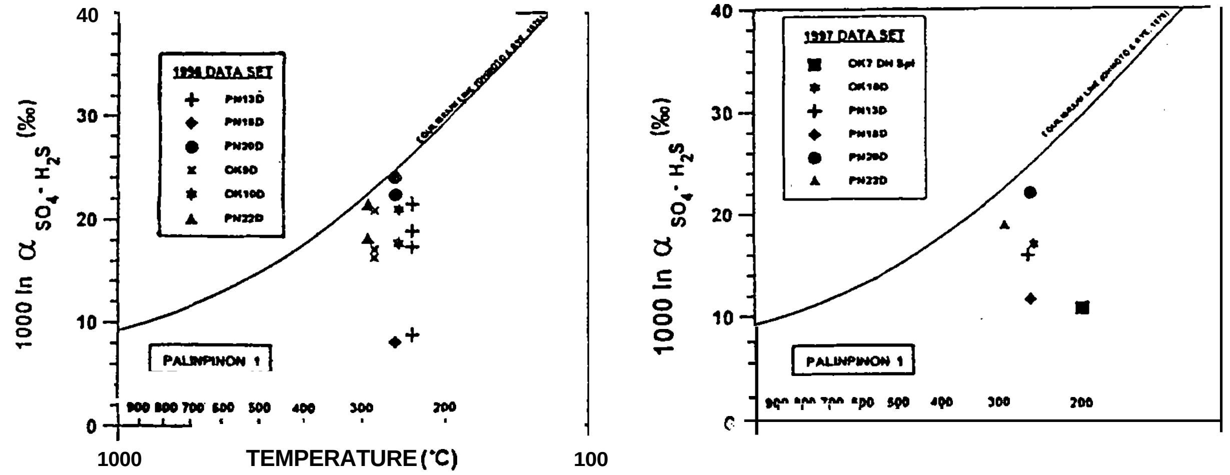

Fig. 4. Sulfate-sulfide fractionation factors versus measured temperatures for Palinpinon 1 wells (equation for equilibrium line after Ohmoto and Rye, 1979).

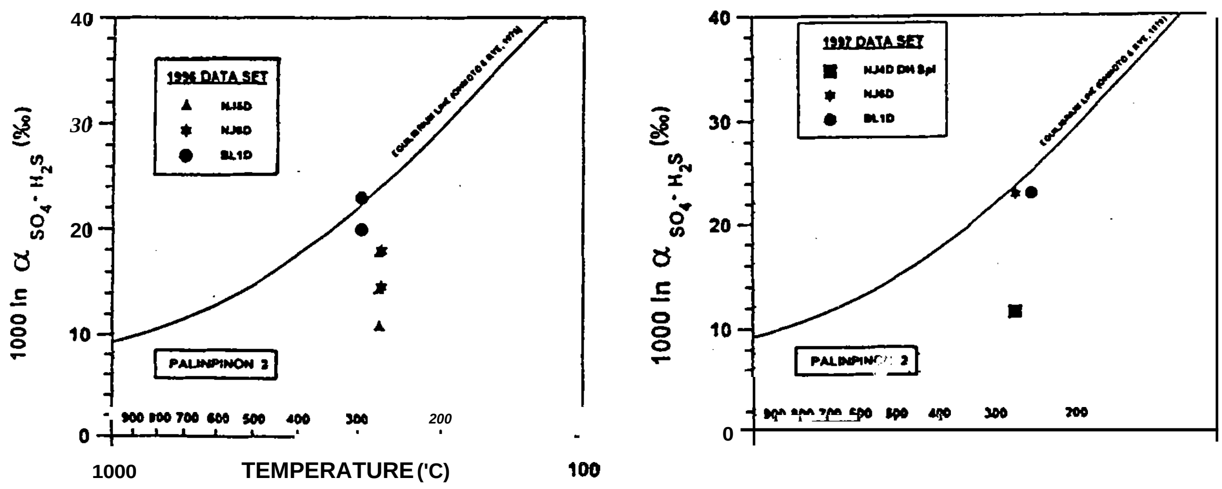

Fig. 5. Sulfate-sulfide fractionation factors versus measured temperatures for Palinpinon 2 wells (equation for equilibrium line after Ohmoto and Rye, 1979).

Wells PN20D, PN22D, BL1D and NJ6D are all located less than a kilometer away from the postulated hydrological upflow zone beneath the Lagunao dome where temperatures as high as 325°C have been encountered. To calculate for the total sulfur of the geothermal system, the following equations were used:

$$\text{Total Sulfur in Water (Sw)} = [\, mH_2S * (S/H_2S)_{fw}\,] + [\, mSO_4 * (S/SO_4)_{fw}\,] + [\, mHSO_4 * (S/HSO_4)_{fw}\,] \quad (1)$$

$$\text{Total Sulfur in Gas (Sg)} = [\, mH_2S * (S/H_2S)_{fw}\,] + [\, mSO_2 * (S/SO_2)_{fw}] + [\, mHS- * (S/HS-)_{fw}\,] \quad (2)$$

$$\text{Total Sufur (IS)} = Sg + Sw \quad (3)$$

Where: m = concentration in molal values; fiv = formula weight of S, H_2S, SO_4, etc.

Resultant calculations for the aforementioned wells gave values in the vicinity of 10^{-2}.moles/kg H_2O. Reservoir pH calculations using the WATCH speciation software for well BL1D (i.e., the nearest well to the upflow), gave estimates ranging from 3 to 3.5 for the samples used in this paper. Using the derived values, a relatively short equilibration period of 17 days to 140 days was obtained. Thus, any steam heated acidic fluids from the shallow portions of the reservoir that percolate towards the deeper sections of the field could easily attain signatures of equilibrium (and if not interpreted properly, could be mistaken for indications of deep magmatic, acid fluids) due to the prevailing conditions cited by Ohmoto and Lasaga in 1982 (see Figure 6).

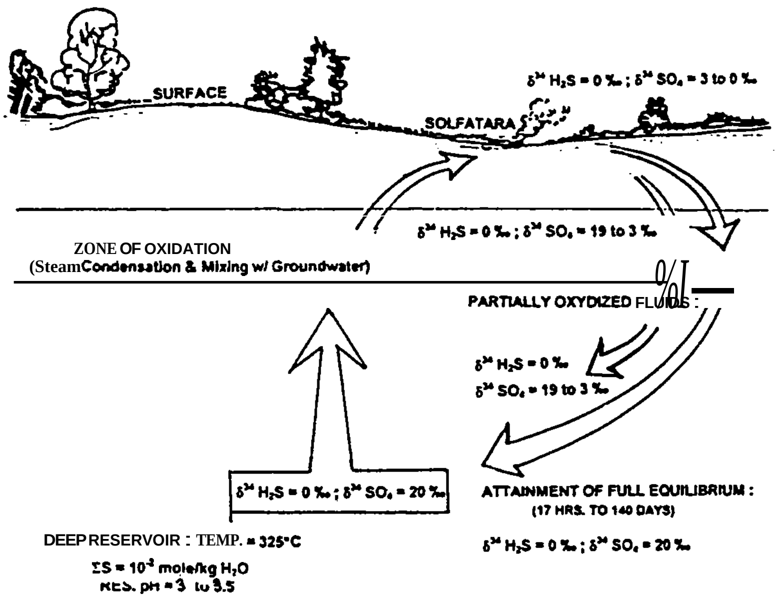

Fig. 6. Proposed model for the Palinpinon Geothermal Field to explain variations in $\delta^{34}S$ in sulfates and sulfides (diagram not drawn to d e)

An iso contour map of the fractionation factors between sulfates and sulfides (1000 In a SO_4 – H_2S) of the Palinpinon samples is shown in Figure 7. This map shows declining values as one moves farther away from the hydrological upflow towards the outflow sectors of the field Thus, for the case of Palinpinon, downhole conditions favorable for the attainment of sulfur isotopic equilibrium are found within southern portion of the field where the upflow is located This is also the place where a significant gas flux emanating from a degassing intrusive body associated with the Lagunao Dome is located (Seastres et al, 19955). This is believed to be the source of CO_2 and H_2S gases that are responsible for the highly acidic downhole conditions and the presence of Kaiphans (i.e., areas of actively forming argillic alteration with surface temperatures close to ambient, and active gas emissions of CO_2 and H_2S – Bogie et al, 1987) within this portion of the field Indications of isotopic disequilibrium (and H_2S partial oxidation) are more evident among wells and thermal features along hydrologic outflow of the system.

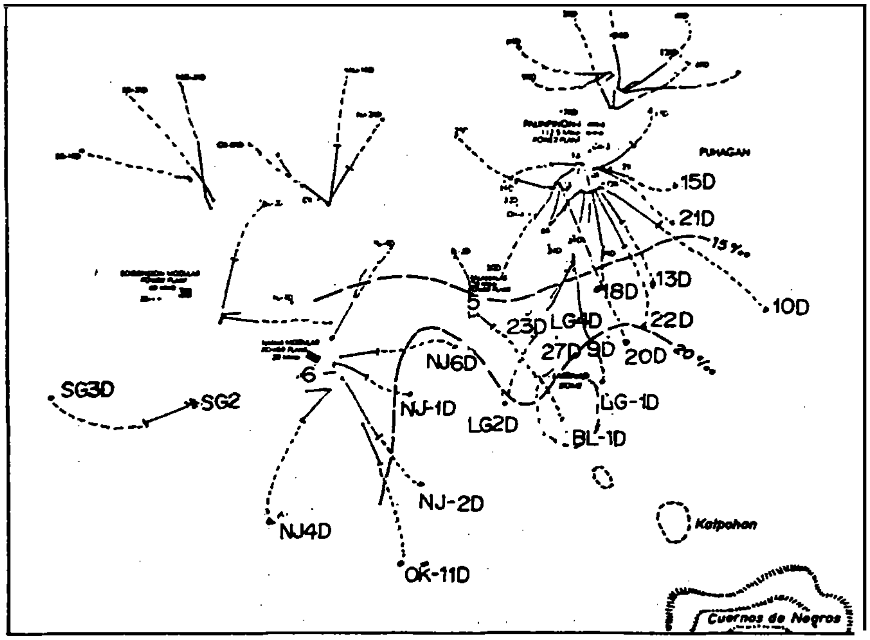

Fig. 7. Iso – $\delta^{34}S$ fractionation factor contour map for the Palinpinon Geothermal Field utilizing 1996 and 1997 data.

2.1.3 OTHER EVIDENCES FROM $\delta^{18}O$ AND DEUTERIUM DATA

Figure 8 shows a plot of Deuterium versus $\delta^{18}O$ data obtained from neutral chloride and acidic production wells near the upflow region of field together with those from the Kaipohan area (Candelaria, 1992). Kaipohan fluids are generally acid sulfate in nature and are considered as positive products of shallow steam heating processes – Bogie et al, 1987). As can be seen in this plot, dilution lines from acidic wells BL1D and LG1D generally terminate into the Kaipoban end member along the SNMWL indicating genetic connection between the fluids. This is another evidence that deep magmatic, acid waters are not currently encountered within the Palinpinon Geothermal Field

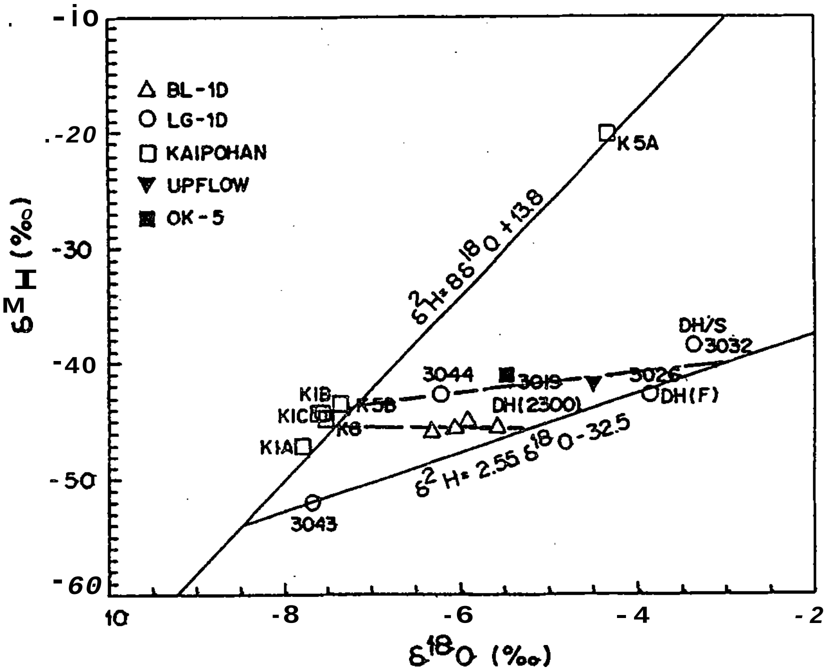

Fig. 8. δ2H vs. δ18O of acidic Palinpinon well near the hydrological upflow. Data from Kaipohan springs also included (data after Candelaria, 1992).

3.0 CONCLUSIONS

Based on **sulfur,** oxygen and deuterium isotope evidences, the acidic fluids encountered within the Palinpinon Geothermal Field originated from the shallow sections of the reservoir where partial oxidation of H_2S *gas occurs.* Based **on** petrographic and physical evidences, acid fluids formed from this mechanism altered volcanic and igneous lithologies along depths ranging from +500 mAMSL to –1500 mAMSL. The H_2S gas within the reservoir is magmatic in origin and generally constitutes a large **gas flux** emanating from a degassing intrusive body within the postulated upflow of the system generally emplaced beneath the Lagunao Dome. **This gas** flux is responsible for the **high** *gas* concentrations in nearby acidic wells BL1D, NJ6D, PN20D and PN22D; and also for the formation of extensive tracts of Kaipohans along the northeastern flank of the Cuernos De Negros Volcano. **These** acid waters **are** generally **drawn** deep into the reservoir by the large pressure differential caused by the **continuous** production of the field **Sulfur** isotopes in sulfates and sulfides attain **full** to partial equilibrium conditions along the upflow sector of the reservoir where low pH, high temperatures **and** high total sulfur compositions promote 90% equilibration **within** a *span* of 17 to 140 days. Due to this site-specific characteristic associated with the Palinpinon Geothermal Field, *sulfur* isotopes may not be effective in detecting deep seated, magmatic acid fluids. Nevertheless, **sulfur** isotopes proved accurate in detecting the presence of steam heated acid waters through the determination of various indications **of H_2S partial** oxidation **through** the methods stated in sections 2.1.1 and 2.1.2 of this paper.

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