

APPLICATION OF STABLE ISOTOPES IN EVALUATING THE RESERVOIR CHANGES AT PALINPINON GEOTHERMAL FIELD DURING EXPLOITATION

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Abstract

Stable isotope studies were conducted to evaluate the reservoir changes observed at Palinpinon during exploitation. Mass breakthrough of reinjection fluids was detected since steam extraction for electric power generation started in 1983. Wastewater injection was shifted in 1989 to the Ticala-Malaunay sector to arrest bore output deterioration caused by reinjection fluid returns during infield injection at Puhagan.

Correlation of isotopic data with geochemical monitoring parameters indicates the following reservoir changes.

- 1. The isotopically enriched ($-2.80\text{‰ } \delta^{18}\text{O}$) reinjection fluid primarily originating from the Ticala sector has invaded southwestern Puhagan thru the Ticala fault. Reinjection fluids from this sector suppressed the entry of acidic fluids in southeastern Puhagan.*
- 2. Reduced wastewater injection at Puhagan in 1989 and increased mass withdrawal in 1990 induced field pressure drawdown and promoted the expansion of isotopically depleted steam zone ($-6.00\text{‰ } \delta^{18}\text{O}$). However, this zone could collapse to massive southwesterly invasion of Ticala reinjection fluids cannot be prevented.*
- 3. Acid-sulfate fluids at Palinpinon are shallow in origin based on sulfur isotopic studies and probably found within the vicinity of Lagunao and Nasuji domes. These fluids moved in the deeper reservoir thru the Odlumon and Mailig faults. H_2S gas enrichment in the acidic wells are associated with degassing activity of these domes,*

1.0 INTRODUCTION

Stable isotope studies have been conducted at Palinpinon geothermal field to characterize the isotopic composition of meteoric and geothermal waters, determine the location of meteoric water recharge to the system and evaluate the chemical/physical processes affecting the reservoir fluids during exploitation (Clemente, 1986; Gerardo et al., 1993). Consequently, stable isotope samples were routinely collected at Palinpinon since January 1992 to assess the field changes in the reservoir with exploitation. Isotopic sampling, however, was mainly conducted at Puhagan in Palinpinon and only samples from selected Nasuji - South Lagunao wells were obtained.

Bore output deteriorations observed in several production wells from 1983 to 1989 due to massive reinjection fluid returns caused by infield injection at Puhagan (Figure 1) prompted the shift of the bulk of wastewater injection to the Ticala-Malaunay sector in 1989 (Seastres, 1993; Seastres et al., 1995). This major revision in reinjection strategy has induced field pressure drawdown and an expansion of the steam zone in the reservoir particularly when mass withdrawal was increased in October 1990 due to the commissioning of nearby Panay Island power grid (Seastres, 1993). Some wells (e.g. PN-32D, PN-33) were drilled to exploit the steam zone at Puhagan in order to prioritize production from water depleted feed zones; hence, minimizing the effect of reinjection fluid returns by

reducing the volume of wastewater to be disposed. Moreover, production wells which have high enthalpies (>2500 kJ/kg) from South Lagunao and tapped the **steam zone** will be interconnected to the Puhagan production system by 1995.

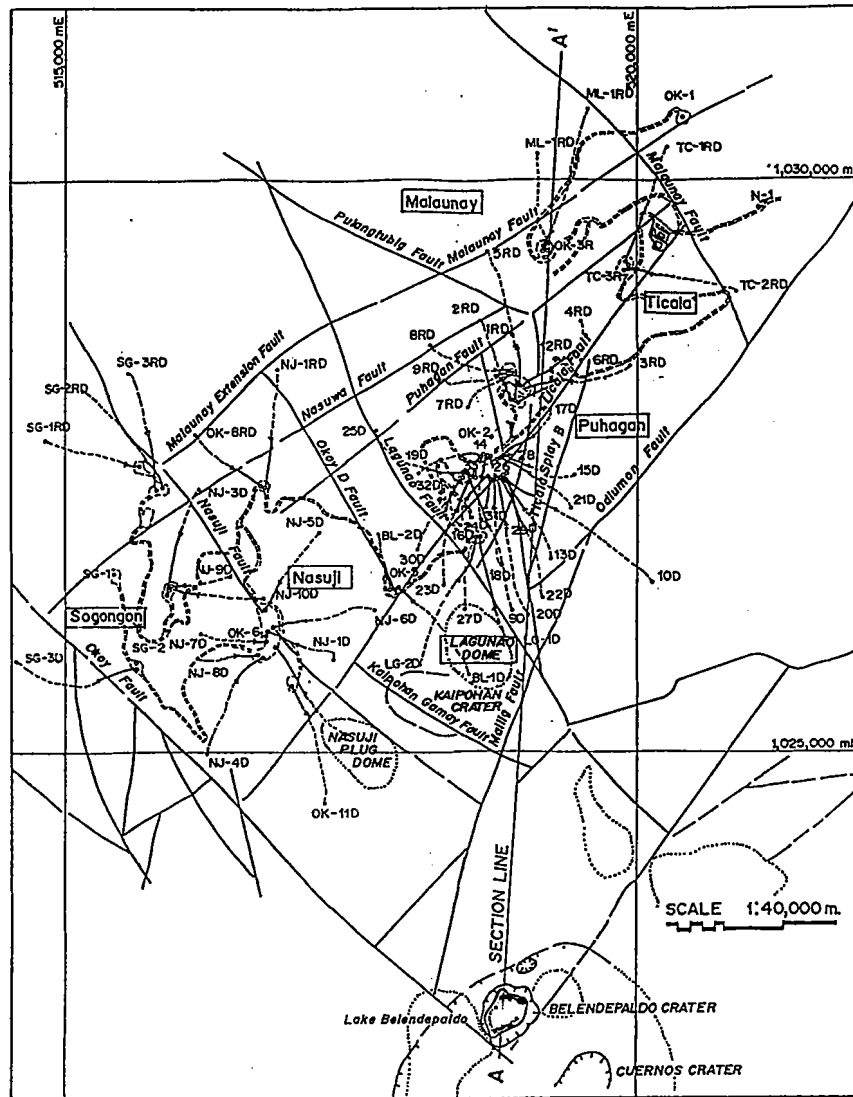


Figure 1. Location map of the Palinpinon geothermal field showing Puhagan, South Lagunao, Nasuji and Sogongon production sectors with the major fault structures. Deviated production wells are marked with a "D". Reinjection wells are marked with "R".

Mass breakthrough of reinjection fluids still occurred at the production sector during the Ticala-Malaunoy fluid injection but migration of these fluids to southeast Puhagan thru Odlumon fault has suppressed the entry of acidic fluids in some production wells (Seastres et al., 1995). However, the migration of these reinjection fluids is limited only to Puhagan and has not reached the acidic wells further south (i.e. from PN-20D to Southern Lagunao wells, LG-ID and BL-1D).

Stable isotopes have been applied to further determine the magnitude of reinjection breakthrough caused by the **shift** of wastewater disposal to the Ticala-Malaunoy sector, evaluate the strategy of producing from the steam zone in the reservoir and to reassess the nature of acidic fluids encountered

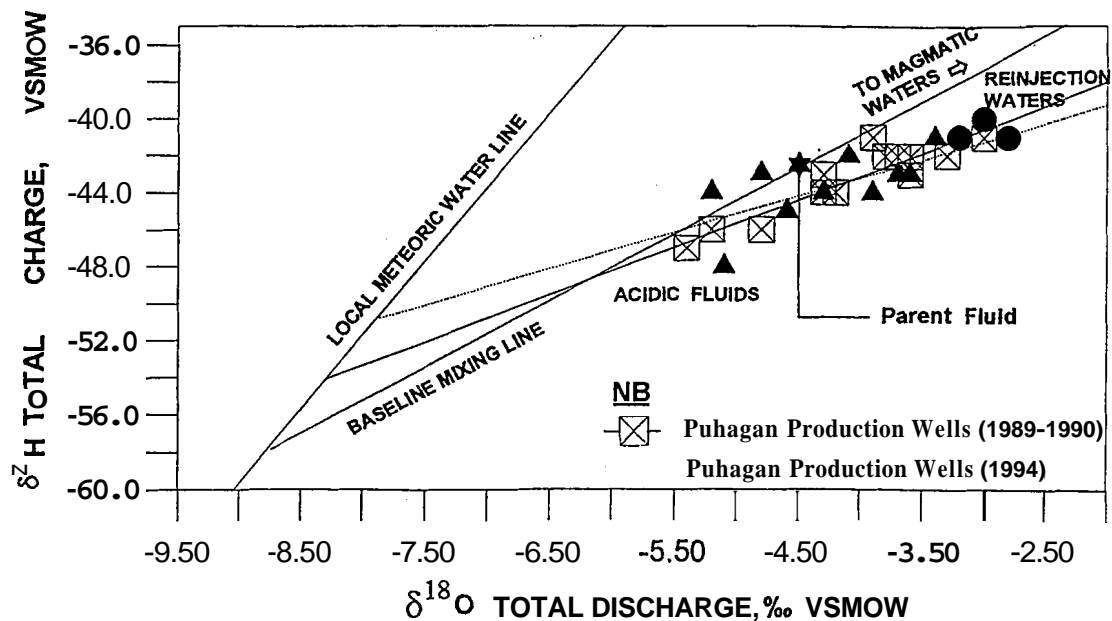


Figure 2. $\delta^2\text{H} - \delta^{18}\text{O}$ isotopic relations showing the deviation from the baseline mixing line defined by $\delta^2\text{H} = -3.5 \delta^{18}\text{O} - 27$ (Gerardo, 1992), due to the inflow of reinjection fluids in the reservoir during field exploitation.

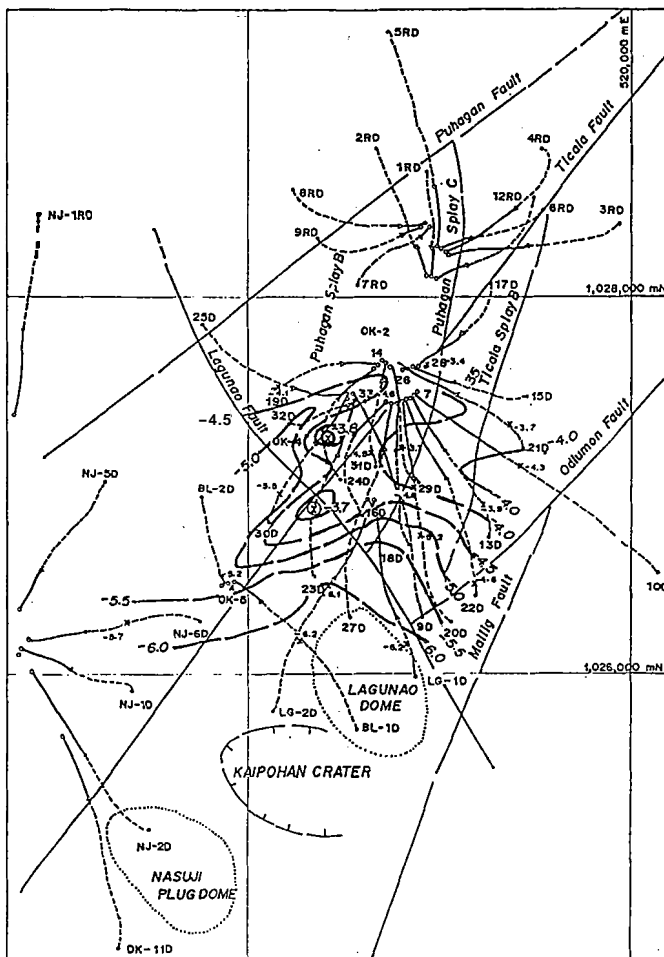


Figure 3. Iso- $\delta^{18}\text{O}$ map illustrating an isotopically depleted steam zone at the South Lagunao sector and an isotopically enriched reinjection mass front at Puhagan.

at Southern Lagunao vis-a-vis Puhagan and Nasuji. In addition, the field hydrological model has been refined based on additional isotopic data to assist, in the formulation of reservoir management strategy in order to optimize steam production from the reservoir.

20 EVALUATION OF TICALA-MALAUNAY REINJECTION STRATEGY

The Palinpinon geothermal fluid is believed to be upflowing at the vicinity of Lagunao dome (Figure 1) with measured temperature reaching as high as 320°C within this sector (Amistoso et al., 1990). The upwelling parent fluid is postulated to be a mixture of 80% meteoric water and 20% magmatic water based on extrapolation of pre-exploitation isotopic data from the baseline mixing line (Gerardo et al., 1993).

The isotopic data during exploitation indicate that the mixing line has deviated from the baseline due to the inflow of reinjection fluids (Figure 2). In the early stage of Ticala-Malaunay injection (1989-1990), the fluid composition of Puhagan production wells has shifted towards the reinjection water end member with an isotopic composition of $-3.0\text{‰ } \delta^{18}\text{O}$ and $-40\text{‰ } \delta^2\text{H}$. An evaluation of isotopic trend in 1994 suggests that the exploitation mixing line has deviated since the start of Ticala-Malaunay fluid injection in October 1989. This isotopic change is attributed to the breakthrough of reinjection fluids from the Ticala-Malaunay sector to the Puhagan production sector now defined by an isotopic composition of $-2.8\text{‰ } \delta^{18}\text{O}$ and $-41\text{‰ } \delta^2\text{H}$.

The flowpath of the Ticala-Malaunay wastefluids is illustrated by the iso- $\delta^{18}\text{O}$ contours (Figure 3) which suggest that the major fluid channel of these reinjection fluids is the Ticala fault. This structure loads majority of the wastewater returning from TC-3R (Figure 1) to the production sector. The wastefluid being disposed at TC-3R is around 180 kg/s. The movement of the Ticala-Malaunay reinjection fluid thru the Ticala fault has reached the margins of southwestern Puhagan within the vicinity of PN-30D although its $\delta^{18}\text{O}$ composition of -5.60‰ is still characteristic of isotopically depleted fluids from the steam zone. If high wastewater load is sustained at the Ticala-Malaunay sector particularly at TC-3R, thermal deterioration in high temperature, good steam producers at southwest Puhagan will be encountered. In fact, the discharge fluid of PN-23D in this sector has been isotopically enriched (i.e. its $\delta^{18}\text{O}$ of -3.7‰ is almost similar with the $\delta^{18}\text{O}$ of -3.4‰ for PN-28 which is highly saturated with reinjection fluids, c. 90%). The discharge enthalpy of this well has deteriorated from 1500 kJ/kg in 1989 to 1270 kJ/kg in 1994.

The breakthrough of Ticala-Malaunay reinjection fluids from TC-2RD to the southeastern production wells with acidic fluid component thru the Odlumon fault is not well-defined by the isotopic contour since the $\delta^{18}\text{O}$ contours farther to the southeast remains open. However, it appears that the Ticala wastefluids have been partly channeled from Odlumon fault near OK-10D towards the central and southwestern production sector (Figure 3). The nature of permeability control is not yet clear at this stage.

3.0 IMPLICATION OF ACIDIC FLUID INFLOWS IN THE RESERVOIR

Acidic fluids detected in the southeastern Puhagan wells (OK-IOD, PN-13D, PN-20D and PN-22D) have low pH (≤ 4.0), high reservoir sulfate ($> 250\text{ mg/kg}$) and high reservoir magnesium ($< 2.5\text{ mg/kg}$). Their gas composition indicates a $\text{CO}_2/\text{H}_2\text{S}$ ratio as low as 10 in PN-20D (Figure 5). Anhydrite often deposited in these wells due to the inflow of acid-sulfate fluids. However, in 1991, the breakthrough of reinjection fluids from TC-2RD to southeastern Puhagan through the Odlumon Fault (Figure 1) has suppressed the inflow of acidic fluids (Seastres, 1991; Seastres et al., 1995). The change in fluid composition was initially observed at OK-10D and PN-13D in 1991 and recently at

PN-22D in 1994. A plot of $\delta^2\text{H} - \delta^{18}\text{O}$ isotopic composition of these wells indicates that the shift is very evident at OK-10D and PN-22D (Figure 4). Well PN-13D, which also had acidic fluid component in its discharge, was already affected by reinjection fluids (i.e. due to reinjection fluid returns from Puhagan) even prior to TC-2RD injection. The minor acid-sulfate fluid component mixing in this well, however, was fully suppressed upon entry of TC-2RD reinjection fluids.

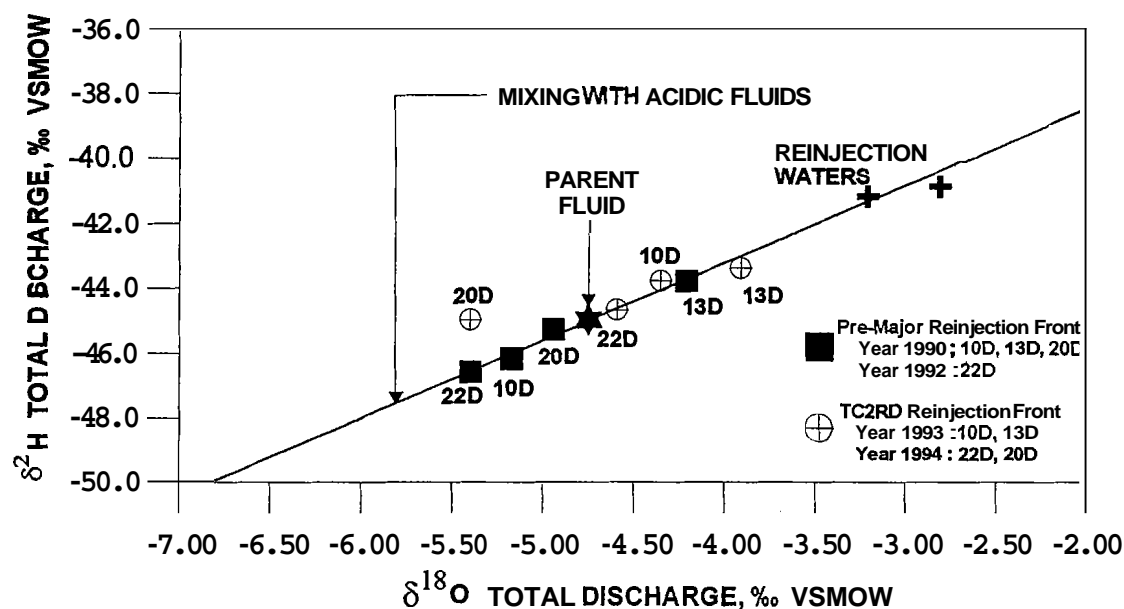


Figure 4. $\delta^2\text{H} - \delta^{18}\text{O}$ relations illustrating the shift of selected Puhagan production wells from mixing with acidic steam condensate fluids to dilution with reinjection waters.

Currently, only PN-20D is still discharging acid-sulfate fluids at Puhagan. The wastewater fluid being loaded at Odlumon fault (i.e. around 60 kg/s at TC-2RD) should be increased to further induce migration of reinjection fluids at PN-20D. A reinjection well, TC-4RD, will be drilled at Ticala in 1995 to increase the wastewater load at Odlumon fault. Enhancing the flow of reinjection fluids through the Odlumon fault to the southeastern Puhagan wells is quite beneficial to the reservoir since the fluid temperature of the wastefluid has been sufficiently reheated allowing a sustained production of relatively hot ($> 260^\circ\text{C}$), near-neutral pH reservoir fluids. Moreover, work-over in these wells to clear the anhydrite blockage and recover steam production were not conducted since anhydrite is not anymore depositing with the full suppression of acidic fluid inflows.

Evaluation of $\delta^{18}\text{O} - \text{CO}_2/\text{H}_2\text{S}$ relation (Figure 5) indicates that the acidic fluids at Puhagan and Nasuji-South Lagunao have different mixing lines. Additional isotopic data will be obtained at Nasuji-South Lagunao to further define the mixing line in this sector. Nonetheless, the lower end member of these sectors appear to have a similar acid-sulfate fluid source.

In view of the different $\delta^{18}\text{O} - \text{CO}_2/\text{H}_2\text{S}$ mixing lines (Figure 5) for the above sectors, the $\text{CO}_2/\text{H}_2\text{S}$ ratio characterizing high fluid acidity (i.e. reservoir fluid with $\text{pH} \leq 4.5$ as observed at Palinpinon is unsuitable for production due to extensive corrosion) at Puhagan is much lower (e.g. $\text{CO}_2/\text{H}_2\text{S}$ ratio ≈ 10 at $\text{pH} = 4.0$) compared to South Lagunao and Nasuji (e.g. $\text{CO}_2/\text{H}_2\text{S}$ ratio ≈ 15 , $\text{pH} = 4.0$). The difference in chemical response to acidity in Puhagan is attributed to the mixing of slightly alkaline reinjection waters with the reservoir fluids in this sector.

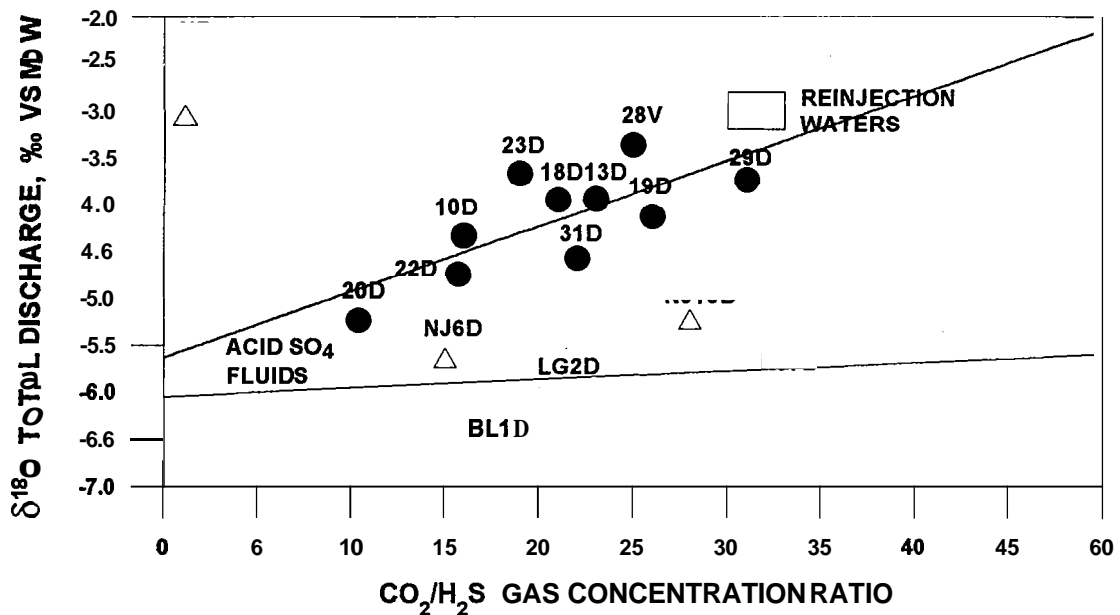
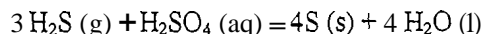


Figure 5. $\delta^{18}\text{O}$ - $\text{CO}_2/\text{H}_2\text{S}$ diagram indicating an increasing $\text{CO}_2/\text{H}_2\text{S}$ ratio towards the reinjection water end member and decreasing $\text{CO}_2/\text{H}_2\text{S}$ upon mixing with acid sulfate fluids.

The nature of fluid acidity at Palinpinon has been variably interpreted by several authors (Harper and Jordan, 1983; Seastres, 1985; Candelaria, 1992). However, characteristics of acidic fluids common for the wells can be distinguished, viz: low $\text{CO}_2/\text{H}_2\text{S}$ gas concentration ratio (10-15), high sulfate (< 500 mg/kg), low chloride (< 1500 mg/kg) and high magnesium (< 4 mg/kg). These chemical concentrations are typical for acidic wells at Puhagan (PN-20D) and South Lagunao (LG-1D, BL-1D). Their relatively low Cl/B ratios ranging from 9 to 13 suggest a common origin for their acidic discharges in contrast to the Cl/B ratio close to 25 in all Palinpinon production wells with neutral pH. At the South Nasuji acid corridor (OK-11D, NJ-1D, NJ-2D and NJ-6D), most of the acidic wells were discharged for relatively short period; hence, chemical stability of the discharges were not attained. However, their initial discharge chemistry approximates the characteristics of the acidic Puhagan - South Lagunao wells except for the $\text{CO}_2/\text{H}_2\text{S}$ ratio which ranged from as low as 2 (NJ-2D) to a maximum of 15 (NJ-6D) and the Cl/B ratio which remained within 25. The very low $\text{CO}_2/\text{H}_2\text{S}$ ratio of 2 reflects acidic H_2S gas enrichment in NJ2D. Its mechanism will be discussed later in this section. The Cl/B ratio of around 25, on the other hand, still indicates a signature of near-neutral pH fluids in the reservoir which could be due to the continued contribution of these fluids to the acidic discharge of South Nasuji wells which were discharged only for a limited period. However, it is expected that the Cl/B ratio of these wells will approximate that of Puhagan-South Lagunao acidic fluids (Cl/B = 10) upon full stabilization of their discharge chemistry. Considering the commonality in the chemical characteristics of the Palinpinon acidic fluids, these fluids were probably generated from a single acidic source that feeds relatively high H_2S gas and high sulfate in the reservoir. The source of this type of acidic fluids are probably found within the vicinity of Nasuji and Lagunao domes (Figure 1).

Sulfur isotope studies conducted at Palinpinon wells by Robinson et al. (1987) showed that the H_2S gas has $\delta^{34}\text{S}$ value of around 0 ‰ which suggests a magmatic origin with no SO_2 gas present in the geothermal field (i.e. all sulfur were interpreted to be present as H_2S). The magmatic gas emanations appear to be primarily consist of CO_2 and H_2S gases. The relatively low $\text{CO}_2/\text{H}_2\text{S}$ ratios in the acidic wells were likely produced by H_2S gas enrichment associated with magmatic degassing at Nasuji and Lagunao domes. Degassing activity, however, is much more extensive within Nasuji

dome ($\text{CO}_2/\text{H}_2\text{S} \approx 2$). Elemental sulfur deposits were recovered at depth (2800 m) in OK-11D which is proximate to **this** dome. These deposits were analyzed to be **as** pure orthorhombic sulfur with a melting point of 113°C and therefore, exists as molten sulfur at depth (Harper and Jordan, 1983). The reaction favoring the formation of elemental sulfur is the following:



High H₂S gas emanations from Nasuji dome probably reacted with sulfate fluids inflowing in the well to form the molten sulfur deposit at OK-11D. The association of high H₂S gas flows with the domes is consistent with the gas seepages at the Kaipohan crater found between the Nasuji and Lagunao domes. The chemistry of Kaipohan cold gas seepages showed a very low CO₂/H₂S gas ratio of 4 (Harper and Jordan, 1983) which is comparable with the low CO₂/H₂S gas ratios at NJ-1D and NJ-2D. Strong H₂S odor and sulfur deposits are characteristics of Kaipohan areas. Their acid-sulfate pools have low pH = 2.82, low chloride = 11 mg/kg and high sulfate = 324 mg/kg (Ruaya, 1980).

H₂S gas enrichment was earlier interpreted to be due to degassing activity associated with the Lagunao and Nasuji domes. The ascending gases enriched with H₂S were eventually oxidized in near surface waters or perched aquifers. Sulfur isotope studies conducted by Robinson et al. (1987) interpreted that the δ³⁴S value (3.5 ‰) close to H₂S in sulfate in originally acidic fluids at Palinpinon (OK-10D, PN-13D and PN-22D) is produced from H₂S oxidation. The more positive δ³⁴S values in sulfate (≤ 23 ‰) of these wells were produced from the downflow of shallow acidic fluids to deeper levels where it gained more positive δ³⁴S values upon isotopic exchange with H₂S. Recent sulfur isotopic analysis (October, 1994) indicates δ³⁴S values in sulfate of 20 ‰ at BL-1D and 22 ‰ at PN-20D which are consistent with the more positive values detected at OK-10D, PN-13D and PN-22D.

The acid-sulfate fluids at Palinpinon reservoir are, therefore, shallow in origin and are found within the vicinity of Lagunao and Nasuji domes. These fluids moved to deeper levels thru the Odlumon fault or Mailig fault in wells PN-20D, LG-1D and BL-1D. Downward movements of acidic fluids in these wells were further induced by field pressure drawdown encountered south of Puhagan. While there is no available sulfur isotope data to indicate the genesis of acidic fluids at Southern Nasuji acid corridor, downhole sampling at NJ-2D in 1983 revealed the presence of blockage above the production casing shoe. The downhole chemistry indicates acidic pH (< 6), high sulfate (< 1900 mg/kg), high magnesium (< 13 mg/kg) and Cl/B ratio of < 13 which suggests a common origin with the acidic fluids of Puhagan and South Lagunao. There is a minimal fluid movement across the blockage (Harper and Jordan, 1983) indicating that the acidic fluid is entering the well NJ-2D above the blockage and likely from shallow levels. The Ticala fault appears to channel the flow of these fluids at Southern Nasuji.

The interpreted genesis of acidic fluids at Palinpinon suggests that drilling within the vicinity of Nasuji dome, Kaipohan crater and Lagunao dome is not feasible since these areas are characterized by relatively high acidic H₂S gas emanations and fault structures hosting the acid-sulfate fluid reservoir. Extensive drawdown in these sectors can easily induced inflow of these fluids from shallow levels. However, increasing the injection load at OK8RD-NJ-1RD sector (i.e. with 60 kg/s fluid acceptance) should be seriously considered to provide fluid recharge to the drawdown Nasuji sector and eventually to suppress the entry of acidic fluids.

4.0 ASSESSMENT OF THE PALINPINON STEAM ZONE

The reduction of mass injection at Puhagan in 1989 coupled with a major increase in mass withdrawal in October 1990 due to the interconnection of Panay power grid has induced a major field pressure drawdown in Palinpinon (e.g. the shut-in pressure of a monitor well, PN-25D, declined from 9 Mpa to 6 Mpa). This phenomenon promoted a general boiling in the reservoir resulting to an

increase in the average field enthalpy from 1500 kJ/kg to 1640 kJ/kg and increase in gas concentrations of several production wells (Seastres, 1993). The reservoir steam fraction of the production wells has increased from an originally liquid deep fluid ($y = 0$) to a highly enriched, two-phase fluid ($y = 0.010$) based on FT-HSH diagram (D'Amore et al., 1993; Seastres et al., 1995). These physical and chemical changes suggest that the two-phase steam zone has significantly expanded with exploitation.

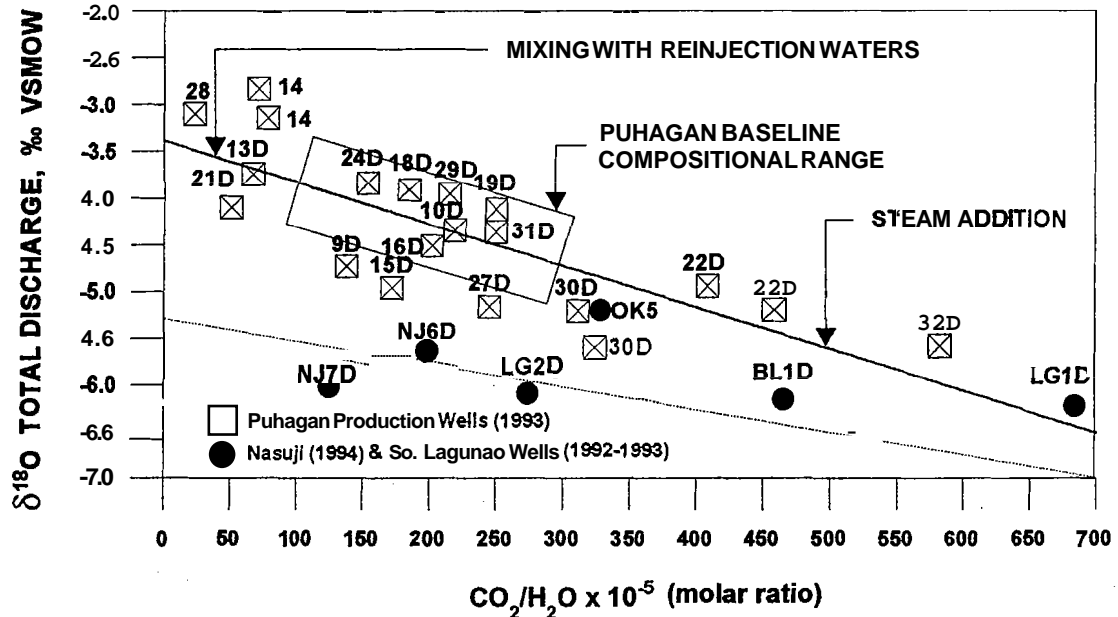


Figure 6. $\delta^{18}\text{O}$ versus $\text{CO}_2/\text{H}_2\text{O}$ diagram during exploitation illustrating the mixing of reservoir fluid with reinjection waters and steam addition for wells relatively unaffected by reinjection fluid returns. Mixing line is defined by $\delta^{18}\text{O} = -4.5 \times 10^{-3} (\text{CO}_2/\text{H}_2\text{O}) - 3.4$.

The expansion of the Palinpinon steam zone is illustrated by the $\delta^{18}\text{O} - \text{CO}_2/\text{H}_2\text{O}$ diagram (Figure 6) which showed that the composition of wells PN-30D and PN-22D have moved from the isotopically enriched baseline range towards the isotopically depleted steam addition zone. This condition indicates that more steam have entered these wells with exploitation as induced by field pressure drawdown. Wells drilled during the exploitation stage, viz: PN-32D and LG-ID, have tapped the expanded steam zone in the reservoir. The plot of these wells within the $\delta^{18}\text{O} - \text{CO}_2/\text{H}_2\text{O}$ mixing line of the Puhagan wells suggest that the high enthalpy, nearly single phase steam discharges of these wells were produced from fieldwide boiling in the Puhagan reservoir.

A plot of the $\delta^{18}\text{O}$ and discharge enthalpy of Puhagan production wells (Figure 7) illustrates that the increasing discharge enthalpy is consistent with the increasing $\text{CO}_2/\text{H}_2\text{O}$ molar ratio (Figure 6) and declining $\delta^{18}\text{O}$ isotopic composition. This trend is an indication that vapor addition facilitated by general reservoir boiling due to field pressure drawdown resulted to an increase in the discharge enthalpies of the production wells. A well, therefore, with a relatively high $\text{CO}_2/\text{H}_2\text{O}$ molar ratio would have a very high discharge enthalpy (e.g. LG-ID). This geochemical monitoring parameter ($\text{CO}_2/\text{H}_2\text{O}$) would provide a good estimate of the discharge enthalpy of production wells at Puhagan.

An overall assessment of the steam zone can be obtained by evaluating the iso - $\delta^{18}\text{O}$ contour at Palinpinon (Figure 3). A highly negative isotopic composition ($\delta^{18}\text{O} = -6.0\text{‰}$) characterized the steam zone found within the southern margins of Puhagan, Lagunao and Nasuji. An isolated region

of less isotopically depleted **steam** zone ($\delta^{18}\text{O} = -5.10\%$) is observed at the western part of Puhagan as encountered by PN-32D. Genetically, however, the steam discharges of LG-ID and PN-32D have evolved from the drawdown induced boiling within the Puhagan sector while wells BL-ID and LG-2D in South Laguna including NJ-6D and NJ-7D in Nasuji have a distinct $\delta^{18}\text{O} - \text{CO}_2/\text{H}_2\text{O}$ mixing line (Figure 6). The latter was likely formed from a more isotopically depleted and diluted reservoir fluid. Drawdown has extended to the Nasuji sector (Amistoso et al., 1990); hence, facilitating the generation of isotopically depleted **steam** zone in this sector.

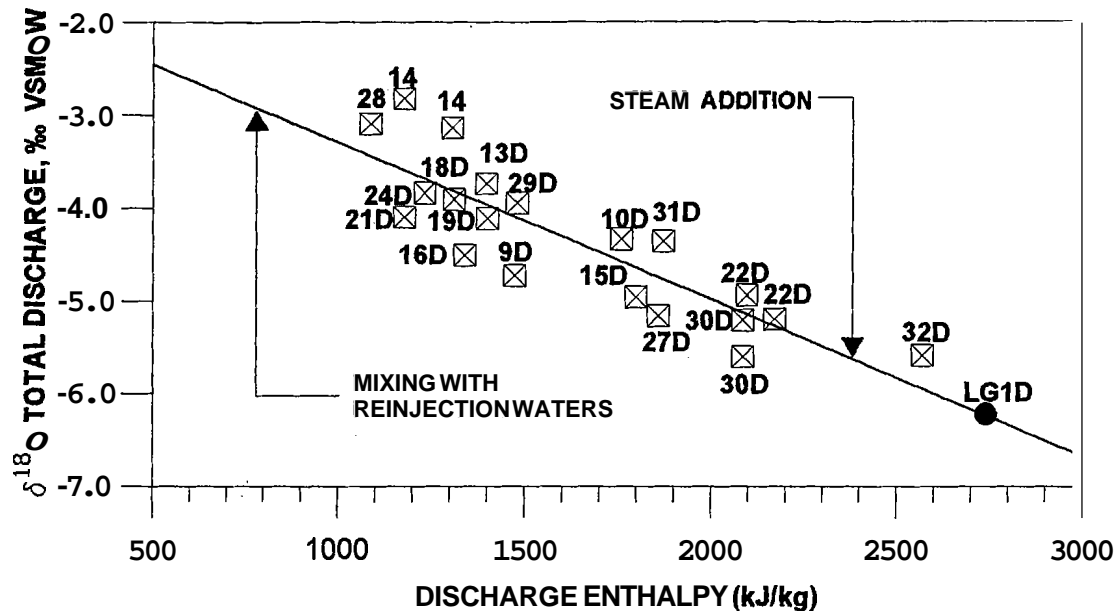


Figure 7. $\delta^{18}\text{O}$ - discharge enthalpy relation of Puhagan production wells indicating the changes in enthalpy due to **mixing** with reinjection waters and to **steam** addition caused by reservoir boiling (ie. induced by field pressure drawdown).

The **steam** zone at Palinpinon appears, therefore, extensive at the southern sector of the Puhagan field and extending towards the South Laguna - Nasuji sector. Field pressure drawdown are prevalent where wells are relatively unaffected by reinjection fluid returns. However, the steam zone particularly at Southern Puhagan could collapse if the massive southwesterly invasion of the Ticala reinjection fluid cannot be prevented. The development of the steam zone at Palinpinon could be sustained provided that reinjection fluid returns are limited to around 30% at the southern and southwestern production wells in Puhagan. Pressure support of within 30% is necessary to maintain fluid recharge in the system. It was observed that discharge enthalpies stabilized within 2000 kJ/kg at the southern/southwestern Puhagan wells with around 30% reinjection fluid in their total discharge. While producing from the steam zone is quite attractive, some wells possessing **high** enthalpies are characterized by acidic fluid discharges (e.g. PN-20D, LG-ID and BL-ID). These wells have intersected the Odlumon and Mailig faults which channeled the acidic fluids generated within the Laguna dome. These fault structures should be avoided in exploiting the steam reservoir south of Puhagan.

5.0 HYDROLOGICAL MODEL DURING FIELD EXPLOITATION

The hydrological field model during exploitation has been refined (Figure 8) based on correlation of isotopic data with geochemical parameters. The parent fluid upwelling south of

Lagunao is believed to be a **mixture** of 80% meteoric water and 20% magmatic water (Gerardo et al., 1993). The magmatic water consists predominantly of CO_2 and H_2S gases. **Sulfur** isotopic studies do not indicate the presence of SO_2 gases. The vapor emanating from a magmatic source interacted with shallow groundwater forming acidic fluids (perched aquifer) near Nasuji and Lagunao domes. It is further released at the surface to form acid-sulfate pools and *sulfur* deposits particularly at the **Kaipohan** areas. The reservoir fluid is recharged by a deeply circulating meteoric water at a minimum altitude of infiltration of 890 m asl (Gerardo, 1992). The isotopic composition of Belendepaldo lake waters is quite distinct ($-5.74 \delta^{18}\text{O}$ and $-38.9 \text{‰} \delta^2\text{H}$) indicating no hydrological connection with the Palinpinon geothermal system.

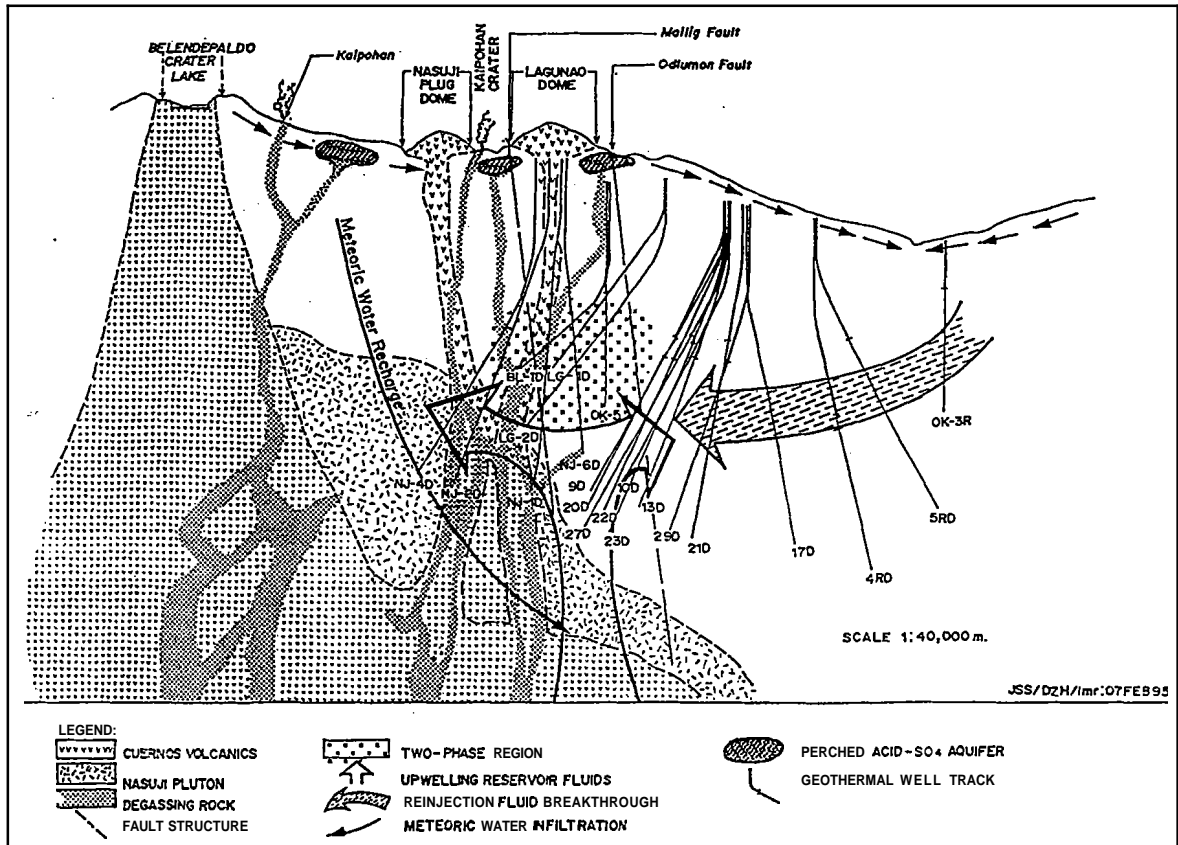


Figure 8. Hydrological model of the Palinpinon geothermal field during exploitation. Section line cut across the field based on line A-A' in Figure 1.

During exploitation, isotopically enriched (c. $-2.80 \text{‰} \delta^{18}\text{O}$) reinjection fluids have migrated primarily **from** the Ticala sector towards southwestern Puhagan thru the Ticala fault. Mass breakthrough of reinjection fluids **from** Ticala (TC-2RD) to southeastern Puhagan thru the Odlumon fault also occurred which suppressed the acid-sulfate fluids inflowing in OK-IOD, PN-13D and PN-22D. With minimum recharge of reinjection fluids south of Puhagan, extensive field pressure drawdown occurred especially during the shift of fluid injection from Fbhagan to the Ticala-Malaunay sector in 1989 and during the major increase in mass withdrawal in 1990. This condition favored the expansion of the isotopically depleted steam zone ($-6.00 \text{‰} \delta^{18}\text{O}$) in the reservoir. The expanded steam cap was intersected by wells at the southern margins of Fbhagan, Lagunao and Nasuji (e.g. PN-30D, LG-ID, BL-ID, OK-5, NJ-6D, LG-2D). However, some of these wells encountered inflows of acid-sulfate waters (LG-ID, BL-ID, NJ-6D) from shallow levels thru fault structures. These acidic fluids originated within the vicinity of Lagunao and Nasuji domes. Acidic H_2S gases from these degassing domes condensed in shallow groundwater aquifers to form acidic fluids. High H_2S gas

emissions promoted the generation of molten *sulfur* deposits at OK-11D in South Nasuji. The Palinpinon hydrological model will be further refined by the *sulfur* isotope studies to be conducted in 1995 to further confirm the genesis of acid-sulfate fluids particularly at South Lagunao and South Nasuji sectors.

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