

EVALUATION OF PALINPINON REINJECTION WELLS FOR THE TOP ZONE PLUGGING OPTION USING LIQUID LCM

Danilo Z. Hermoso

PNOC-EDC, Southern Negros Geothermal Project, Negros Oriental, Philippines

Abstract

Ten reinjection wells in the Puhagan sector of the of the Palinpinon geothermal field were evaluated for their viability in the proposed top zone plugging work-over scheme using the "liquid LCM" method. This work-over technique is one of the mitigating measures being considered to alleviate the problem on thermal deterioration among production boreholes due to reinjection returns. This will be carried out by sealing off the highly communicative, shallow permeable zones within the nearby reinjection wells. This scheme involves the utilization of a mixture composed of calcium chloride and sodium silicate to isolate the annulus of the well's slotted liner section before conventional cement plugging is conducted to seal off the recalcitrant permeable zones.

Evaluation results revealed that the top zone plugging option could be conducted on three particular reinjection wells. The eventual work-over of these wells is being eyed to give substantial remedy to the problem on reinjection returns in the Palinpinon geothermal field.

1.0 INTRODUCTION

Thermal deterioration due to reinjection returns has been a major problem in the Palinpinon-I production field since steam production for power generation began in 1983. Thermal effluents injected into the reinjection wells in the area returned rapidly to the production sector through a series of interconnected northeast and northwest trending faults that cut across the field. Numerous remedial measures have been implemented in the past with limited degrees of success. From 1983 to 1989, fluid reinjection at the Puhagan area was shifted from sector to sector at varying periods to minimize the effects of reinjection returns to the production wells. However, this procedure failed.

As of September 1994, only 2 out of the 10 reinjection wells in Puhagan were left on-line to the FCDS (i.e. PN5RD and PN2RD). Based on the results of the ongoing reinjection breakthrough monitoring being conducted on the site, 65 % of the production wells in Puhagan have been proven positive for thermal deterioration due to reinjection returns. Production wells from the southeastern, central and southwestern sectors of the field have experienced downhole temperature declines ranging from 10°C to 20°C as a result of the influx of insufficiently reheated reinjection brine originating mainly from PN2RD.

The wholesale relocation of reinjection loads to wells located along the postulated outflow of the reservoir has been the primary reservoir management strategy used to address the problem. Another mitigating measure currently being implemented is the utilization of wells with steam dominated discharges that eventually produce minimal water fractions.

Recently, the option to case off the upper zones of selected reinjection wells in the Puhagan area was raised as an alternative in solving the problem on reinjection breakthrough. This new drilling technology basically involves the mixing of sodium silicate and calcium chloride along a section of the slotted liner to create a quick setting resin-like material. As a result of its viscous nature, this mixture will eventually isolate the section of the hole, including the annulus, and act as bridge plug that will

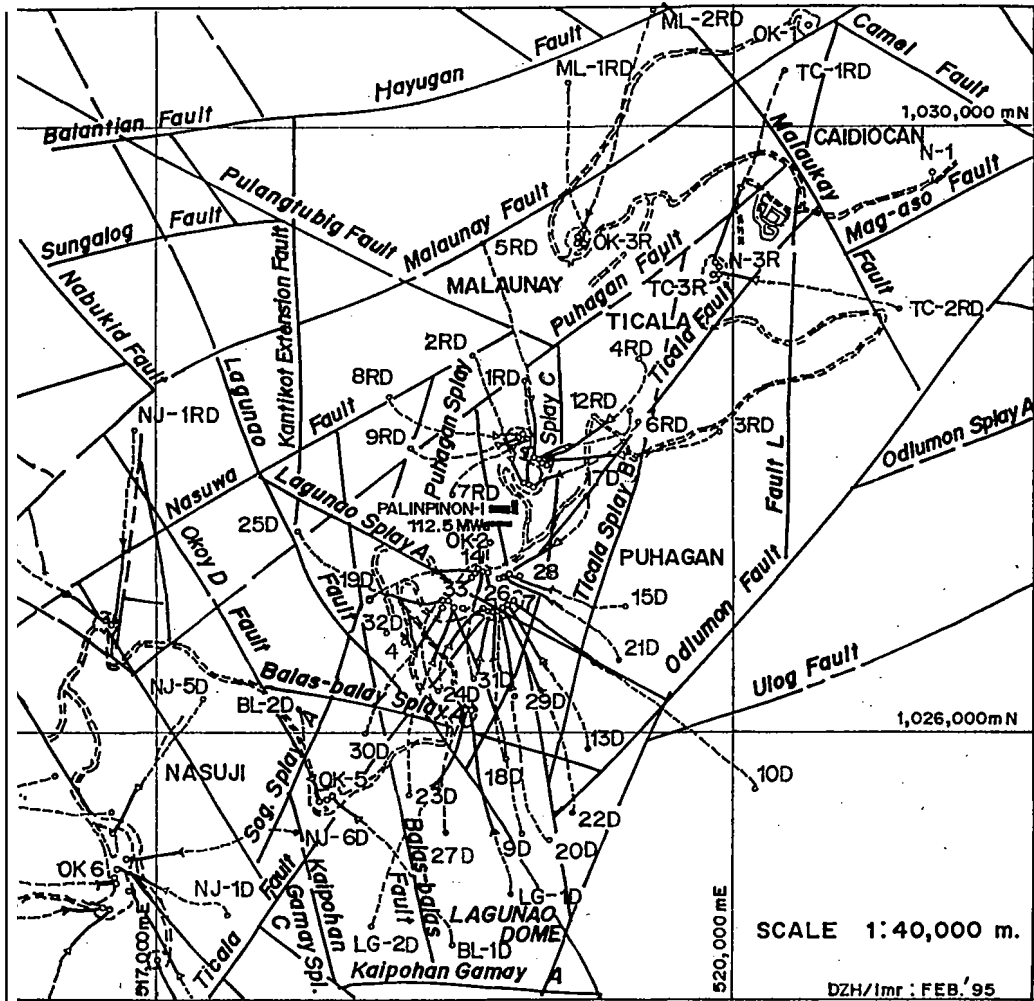


Fig. 1 Map of the Palinpinon-I production field showing location of production and reinjection wells. Mapped geologic structures are also shown. Reinjection wells possess "R" in their designations.

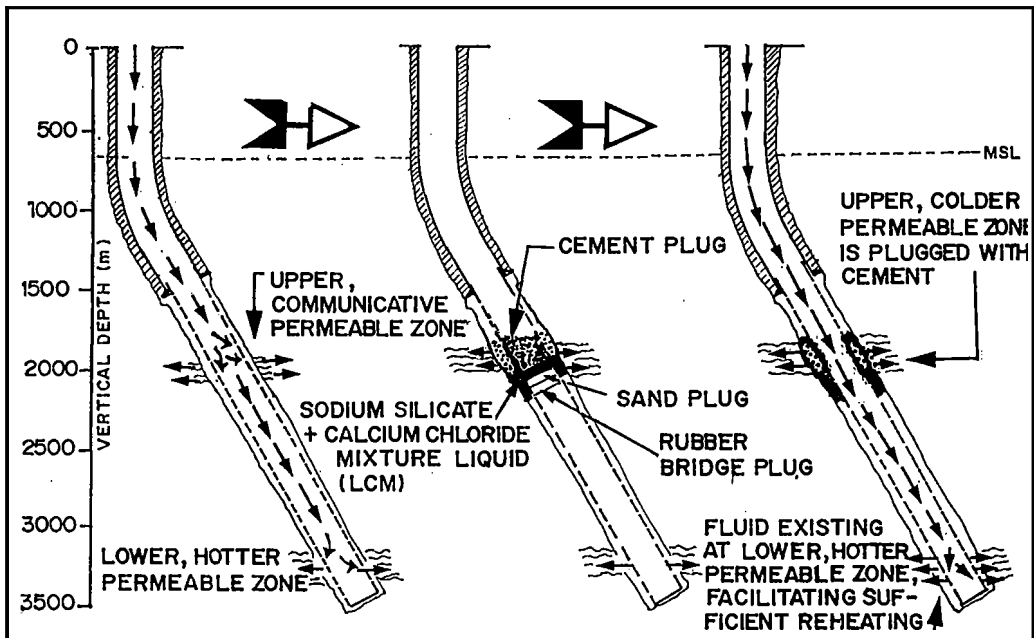


Fig. 2 Simplified schematic diagram for the top zone plugging option using "liquid LCM." 56

facilitate the cementing of the upper sections of the hole. The isolation of the upper permeable zone of the reinjection well is expected to achieve the following :

- a. prevent the entry of cold, insufficiently reheated reinjection brine in the reservoir's plumbing system and:
- b. promote the efficient reheating of the reinjected brine by permitting it to proceed deeper into the lower, hotter portions of the well before it re-enters the reservoir's convective system.

If proven successful in eliminating communications between the reinjection and production sectors, this new drilling technology will enable the re-use of currently "condemned" reinjection wells in Puhagan. Furthermore, this option may provide a cheaper and faster alternative to the drilling of new wells that will be used to take up the additional injection loads in the future.

2.0 WELL EVALUATION AND SELECTION

2.1 Selection Criteria and Evaluation Method

The criteria for the selection of candidate reinjection wells for the top zone plugging option are listed as follows:

- a. A candidate well should possess a shallow permeable zone that is confirmed to promote communications with other production wells in the Puhagan area.
- b. Having fulfilled criterion "a", the remaining permeable zones of the candidate well should not be expedient in rapidly channelling the injected fluids back to the production sector. These permeable zones should be located deep enough within the well to promote the reheating of the reinjected brine.

To aid in the selection process, permeability controls of the 10 reinjection wells in Puhagan were initially determined. Emphasis was placed on the determination of the specific faults or geologic structures that are influencing the various permeable zones in each well. Fault dip ranges were determined through the use of graphical trigonometric solutions that were confirmed through computer aided calculations. Once these data are available, the probable fluid flow paths from each individual permeable zones are traced on the structural map to determine if these are heading towards the production sector or not. The final results are evaluated against the above mentioned criteria to come up with the final list of selected wells.

2.2 Analysis

To facilitate an organized discussion of the conducted analysis, the reinjection wells in the area were categorized according to the general sectors that they were drilled into. The general groupings are given as follows:

Eastern Sector - PN3RD, PN4RD, PN6RD and OK12RD

Northern Sector - PN1RD, PN2RD and PN5RD

Western Sector - PN7RD, PN8RD and PN9RD

2.2.1 Eastern Sector

The upper zone of well PN3RD at 1867-2133 mMD (1800-2050 mVD) is controlled by the Ticala Splay B Fault along a dip range of 87° to 89°NW. This structure is believed to be responsible for

promoting reinjection breakthrough in wells PN15D, PN21D, PN13D and PN22D. Sealing off this particular permeable mne will certainly reduce PN3RD's ability to communicate **with** the production wells situated in the southern and southeastern portion of the borefield. The middle permeable zone in this well at 2292-2503 mMD (2200-2400mVD) could not be correlated with any of the mapped structures in the vicinity and is believed to be controlled by an unmapped or buried geologic structure. The major permeable zone at 2938-3150 mMD (2800-3000 mVD) is attributed to the intersection of the northeasterly trending Fault L along a dip range of **80°-83°** NW. Fluids entering this permeable mne will follow a circuitous route back to the eastern and southern production wells via the Odlumon Fault. This long, sinuous **flow** path is deemed auspicious because sufficient reheating of the reinjected brine **will** definitely occur.

Wells PN4RD, PN6RD and OK12RD are considered unsuitable for the top zone plugging option. Structural analyses conducted on these wells show that the lower zones in these boreholes are controlled dominantly by two highly permeable structures that **will** eventually cause the rapid return of insufficiently reheated reinjected brine back to the production sectors. These structures are the north-easterly trending Ticala and Ticala Splay B faults. Experience in well TC3R injection showed that despite the 2 km. **aerial** distance separating this well and the Puhagan production sectors, cold reinjected brine is rapidly coursed back to Puhagan through these 2 highly permeable structures to cause widespread thermal deteriorations **in** wells like PN28, PN31D PN 16D PN24D PN23D, PN30D, PN17D, PN15D, PN21D, PN22D and PN29D.

The upper permeable zones in PN4RD, PN6RD and OK12RD are also too near to the production borefield (i.e. 700 to 800 m to the nearest production well) to cause any effective reheating to occur **in** the injected fluids. Injection **along** the shallow portions of the reservoir **will** also lead to the eventual collapse of the postulated steam cap which is already being exploited by some production wells **in** the Puhagan area.

TABLE I
List of Permeability Controls for Eastern Sector Reinjection Wells

Well Name	Permeable Zone (mMD/mVD)	Per.Zone Type	Permeability Control
PN3RD	1867-2133/1800-2050 2292-2503/12200-2400 2938-3150/2800-3000	Minor Minor Major	Ticala Splay B (dip= 87°-89° NW) Buried or Unmapped Fault Fault L (dip= 80°-83° NW)
PN4RD	2008-2400/1920-2297 2875-300/2759-2881	Minor Major	Ticala Fault (dip= 87°-89° NW) Ticala Splay B (dip= 87°-89° NW) Tical Fault (dip= 87°-89° NE) Ticala Splay B (dip= 87°-89° NW)
PN6RD	915-1200/900-1170 1402-1601/1360-1550 1802-2000/1740-1930	Minor Minor Major	Unmapped Fault or Intraformational Unmapped Fault or Lithologic Contact Ticala Fault (dip= 87°-89° NW)

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TABLE I (Cont.)
List of Permeability Controls for Eastern Sector ReInjection Wells

Well Name	Permeable Zone (mMD/mVD)	Per.Zone Type	Permeability Control
OK12RD	1402-1700/1375-1645 2013-2400/1935-2050	Minor Major	Intraformational or Unmapped Fault Tical Fault (dip=87°-89° NW) Ticala Splay B (dip=87°-89° NW)

2.2.2 Northern Sector

Well PN1RD is interpreted to have drilled intermittently in and out of the Puhagan Splay C Fault throughout the entire extent of its 8-1/2" open hole section. The dip range of this structure is placed at 85° to 87° NW. This fault is interpreted to be highly communicative with production boreholes PN28, OK7, PN26, PN29D, PN20D, OK9D and PN18D. Plugging the permeable zones in PN1RD that are controlled by Puhagan Splay C would entail the cementing of the well's entire 8-1/2" hole section.

Well PN2RD's topmost permeable zone at 1217-1601 mMD (1200-1570 mVD) is believed to be controlled by Fault G along a dip range of 84°- 86° NE. This structure is responsible for the notoriety of PN2RD in causing reinjection breakthrough across the entire Puhagan borefield. Fluids entering this fault are channelled rapidly to the south east where they interface with the fracture networks of the Ticala and the Puhagan Splay C faults. The net result is the widespread thermal deterioration in 13 out of the 20 wells currently hooked up to the 112.5 MWe power plant.

The virulent nature of well PN2RD actually started when the permeability of the topmost zone was inadvertently enhanced during the well's acidizing operation in 1993. Prior to this, PN2RD was not so communicative with the production sectors and was actually ranked # 2 in the area's reinjection well priority list for utilization. The sealing off of the upper production zone of PN2RD is highly recommended.

The middle permeable zone in PN2RD at 2613-2800 mMD (2550-2730 mVD) is considered to be incapable of causing any reinjection breakthroughs in the production sectors. This zone is controlled by the northeasterly trending Puhagan Fault, a structure that is not directly connected to any production well in Puhagan. This fault has a narrow dip range of 89°-89° NW. Experiences in the use of reinjection well PN5RD show that fluids injected in this geologic structure are channelled away to the postulated, north easterly trending outflow tongue of the geothermal reservoir along the lower reaches of the Okoy Valley.

It is prudent to leave PN5RD as it is. This is the only reinjection well in Puhagan right now that doesn't cause chemical or thermal reinjection breakthroughs in any of the production boreholes in the area. The fluids entering this well are channelled away from the producing wells through the Puhagan Fault, the Nasuwa Fault and the Pulangtubig Fault. A minor permeable zone at 1131-1198 mMD (1060-1120 mVD) is intraformational in nature and does not cause any harmful effects to the production boreholes.

TABLE II
List of Permeability Controls for Northern Sector ReInjection Wells

Well Name	Permeable Zone (mMD/mVD)	Per.Zone Type	Permeability Control
PN1RD	1400-1502/1380-1480 1802-2000/1770-1960 2802-2843/2740-2780	Major Minor Minor	Puhagan Splay C (dip =85°-87° NW) puhagan Splay C (dip=85°-87°NW) Puhagan Splay C (dip= 85°-87°NW)
PN2RD	1217-1601/1200-1570 2613-2800/2550-2730 3183-3402/3100-3310	Minor Major Minor	Fault G (dip=84°-86° NE) Puhagan Fault (dip=89°NW-90°) Nasuwa Fault (dip=88°-89°SE) Puhagan Splay B (dip=85°-89°SE) Sogongon Splay A (dip=86°-89° SE)
PN5RD	1131-1198/1060-1120 1470-1708/1350-1550 1885-2119/1700-1900	Minor Major Minor	Intraformational puhagan Fault (dip=89°NW-90°) Nasuwa Fault (dip=88°-89° SE)

2.2.3 Western Sector

Wells PN7RD, PN8RD and PN9RD were all declared unfit for reinjection utilization since tracer tests conducted in 1984, using radioactive isotopes, showed that the **fluids** injected into this sector of the field rapidly returned to the production wells in the central and southwestern portions of the Puhagan area. Tracer return times ranged **from** 26 hours in OK7 to 9.8 days in PNI6D.

As in the case of PN2RD, the structure believed to be behind the virulent nature of the **3** reinjection wells in this sector is Fault G. Wells PN7RD, PN8RD and PN9RD all possess upper permeable zones that are controlled by this structure. The net effect of injecting **fluids** in any of these 3 wells will be field wide reinjection breakthrough facilitated by the interconnection of Fault G to the Ticala and the Puhagan Splay C faults.

The effects of sealing off the upper zones of PN7RD, PN8RD and PN9RD have different magnitudes of auspiciousness. For the case of PN7RD, the lower permeable zone in this well is still proximate to the production sectors to sufficiently reheat the reinjection brine. Another drawback for PN7RD is that this particular lower zone is controlled by a "communicative" geologic structure, the Puhagan Splay B Fault.

Sealing off the upper permeable zone of PN9RD **will** create scenarios **similar** to those in PN8RD. **Fluids** that **will** be injected into the remaining, lower permeable zones of this well **will** rapidly return to the production wells in the south and southwest via the Puhagan Splay A Fault (dip range of 86° to 89° SE). The production wells that are anticipated to be affected by reinjection breakthrough from these faults are :PN25D, PN19D, PN32D, PN14, PN30D, PN24D and possibly, BL2D which has a permeable zone being controlled by the Sogongon Splay A Fault.

Among the 3 reinjection wells in the western sector, it is only PN8RD that possesses considerable advantage if its upper zone **will** be sealed off **This** is borne by the fact that the remaining, lower

permeable zones in this well may not cause any **high** degree of communication with the production boreholes in the southwestern region of **Puhagan**. The middle permeable zone at 1703-1993 mMD (1640-1920 mVD) is controlled by the Sogongon Splay **A** Fault and the "reinjection friendly" Puhagan Fault which was encountered in PN5RD and PN2RD. The lower most permeable zone at 2600 mMD (2500 mVD) is controlled by another "reinjection friendly" geologic structure, the northeast trending Nasuwa Fault.

TABLE III
List of Permeability Controls for Western Sector Reinjection Wells

Well Name	Permeable Zone (mMD/mVD)	Per.Zone Type	Permeability Control
PN7RD	704-859/700-850 994-1300/980-1270 2465-2626/2400-2560	Minor Minor Major	Fault G (dip= 82°-86° NE) Fault G (dip= 82°-86° NE) <i>Puhagan Splay b</i> (dip= 85°-89° NW)
PN8RD	800-993/790-570 1090-1302/1060-1260 1703-1993/1640-1920 2600/2500	Minor Minor Major Minor	Fault G (dip= 82°-86° NE) Puhagan Splay B (dip= 85°-89° SE) Sogongon Splay A (dip= 86°-89° SE) Nasuwa Fault (dip= 88°-89° SE)
PN9RD	1218-1399/1200-1375 2471-2600/2400-2525 2697-2997/2620-2915	Minor Minor Major	Fault G (dip= 82°-86° NE) Sogongon Splay A (dip= 86°-89° SE) Puhagan Fault (dip= 89° NW-90°)

Unlike the lower permeable zones PN9RD and PN7RD that are considered too close to the production borefield, the middle and lower permeable zones in PN8RD are relatively more distant in location which may cause the eventual reheating of geothermal brine that will be injected therein.

In 1984, **Mr. Arturo P. Alcaraz** made a theory that the highly communicative nature of wells PN7RD, PN8RD and PN9RD was controlled by a northwest *trending* structure that was buried beneath young pyroclastics. Dubbed as the "Puhagan Buried Fault", this structure was inferred from the results of the tracer test in 1984 wherein PN9RD was used as the injection well. Using **graphical**, trigonometric solutions, **Mr. Alcaraz** was able to show that this structure was responsible for the similarly aligned bit walks in the 3 wells and was the **main** conduit used by the reinjected brine back to the production sector.

Although this theory still needs further investigation, the possibility still exists that a buried fault may have caused the northwesterly alignment of the bit walks along the lower portions of PN7RD, PN8RD and PN9RD. The controversy behind this theory could only be resolved once the upper zone in PN8RD is sealed off. **If** reinjection breakthroughs are still reported among the production wells in the central Puhagan region despite the work-over, the theory of **Mr. Alcaraz** is valid. However, **if** things improve, the work-over of nearby reinjection well PN9RD could be considered.

3.0 Conclusions

- a. For the eastern reinjection sector, the only well that is eligible for the top zone plugging is well PN3RD. The other wells in **this** sector possess both upper and lower permeable zones that are **highly** capable of communicating with the production wells in **Puhagan**. These permeable zones are controlled by the highly permeable Ticala and Ticala Splay B faults and are located too close to the production wells to **sufficiently** reheat the reinjected brine.
- b. For the northern reinjection sector, sealing **off** the upper zone of PN2RD may enable **this** well to duplicate the favorable characteristics of PN5RD.
- c. For the western reinjection sector, only well PN8RD is eligible for the top zone plugging option. However, if the theory **on** the "Puhagan Buried Fault" is proven correct by the results of the work-over then further injection in **this** well should be discontinued.
- d. Fault G, interconnected with the Ticala and the **Puhagan** Splay C faults, is responsible for the highly communicative characteristics of wells PN2RD, PN7RD, PN8RD and PN9RD. This fault controls all the upper permeable zones of these wells.
- e. Well PN5RD's "reinjection friendly" nature is caused by the influence of two geologic structures that are channelling the injected fluids from **this** well away from the production sectors in **puhagan**. These structures are the northeasterly trending **puhagan** and Nasuwa faults.

4.0 Recommendations

Based from the conducted evaluation, the wells that were recommended for the top zone plugging option (utilizing the "liquid LCM" method) are prioritized **as** follows:

- a. PN3RD with top zone at 1867-2133mMD (1800-2050 mVD)
- b. PN8RD with top zone at 800-1302mMD (790-1260 mVD)
- c. PN2RD with top zone at 1217-1601mMD (1200-1570mVD).

If subsequent reinjection in PN8RD proves to be beneficial (i.e. no reinjection breakthroughs are experienced along the wells in the central and southwestern production wells in **puhagan**), the option to plug the upper zone of PN9RD (1218-1399 mMD; 1375-2400 mVD) might be undertaken. However, if PN8RD **still** remains communicative with the production wells in **Puhagan**, most especially to those located within the central **Puhagan** region, Mr. Alcaraz's theory on the "**Puhagan** Buried Fault" holds credence and further injection along the western reinjection sector should be discontinued.

5.0 REFERENCES

- Alcaraz, A. P. (1984), *A Case for a Puhagan Buried Fault*, PNOC-EDC Internal Report.
- Amistoso, A. E. and Yglopaz, D. M. (1994), *Southern Negros Geothermal Project Well Data and Interpretations*, PNOC-EDC Internal File.
- Fragata, J. J. (1981), *Geology of OK12D*, PNOC-EDC Internal Report.
- Hermoso, D. Z. (1983), *Preliminary Geological Reports of Wells PN4RD and PN7RD*, PNOC-EDC Internal Reports.

- Hermoso, D. Z. (1994), *SNGP Geochemistry Technical Report (June to September 1994)*, PNOC-EDC Internal Report.
- Lapuz, R. G. (1983), *Preliminary Geological Reports of Wells PN5RD, PN6RD, PN8RD and PN9RD*, PNOC-EDC Internal Reports.
- Licup, A. C. (1992), *Guidelines on Geological Reports and Methods of Welltrack Calculation*, PNOC-EDC Internal Report.
- Ogena, M. S. (1984), *Preliminary Geological Reviews of Wells PN1RD, PN2RD, PN5RD, PN7RD, PN8RD and PN9RD*, PNOC-EDC Internal Reports.
- Seastres, J. S. (1983), *Geological Reports of Wells PN1RD, PN2RD and PN3RD*, PNOC-EDC Internal Reports.
- Seastres, J.S. et al. (1994), *Applications of Geochemical Techniques in Evaluating the Reservoir Response to Exploitation at Palipinon Geothermal Field, Philippines, (in Press)*.
- Urbino, M. E. G. (1986), *Structural Flowpaths of Reinjecting Fluids Based on Tracer Tests - Palipinon I. Philippines*. Proceedings, 8th New Zealand Geothermal Workshop.