

CHANGES IN THE APPARENT PIEZOMETRIC LEVELS IN THE PALINPINON FIELD AS A RESPONSE TO TWELVE YEARS OF EXPLOITATION

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ABSTRACT

Field pressure reduction in the Puhagan sector of the Palinpinon Geothermal Field resulted in the depression of the apparent piezometric levels. Drawdown of between 20-300 m centered in Puhagan was observed since the start of power generation in June, 1983 and until October, 1989. Further drawdown of as much as 50 to 520 m was observed centered in Puhagan between 1989 and 1993 as a result of increased mass withdrawal due to the connection of Panay island to the Negros Power Grid in October, 1990. This drawdown in Puhagan has reversed the hydrostatic head between the production and reinjection sectors. This head reversal, along with the permeability of the fault connections and the proximity between the two sectors may enhance the amount and rate at which reinjection fluids flow back to the production area.

1.0 INTRODUCTION

The Palinpinon Geothermal Field is located near the southern tip of the island of Negros in the Central Philippines (Fig. 1). The field has been subdivided into four (4) sectors based on the mode of utilization. The main production field is in the Puhagan Sector (A in Fig.1) where the 112 MWe Palinpinon-1 Power Plant has been in operation since 1983. The 80 MWe Palinpinon-2 Modular Plants in the Nasuji-Sogongon Sector (B in Fig.1) three kilometers to the west were commissioned in 1994. Wells in the Lagunao Sector (C in Fig. 1), about one kilometer south of Puhagan, are to support the Palinpinon-I power station in the event of a shortfall in the steam supply. A modular power station is also installed in the OKS-Balas-balas Sector (D in Fig.1).

The waste water from Puhagan and Balas-balas are disposed into the reinjection wells located in the Puhagan and Ticala-Malaunay (E in Fig.1) reinjection pads. The Puhagan injection wells are located about 500 m northeast of the power station while the Ticala-Malaunay injection wells are about two to three (2-3) kilometers downstream of Puhagan. Waste water in Nasuji-Sogongon are injected in wells in the Nasuji-Sogongon reinjection area about 2 to 3 kilometers north of the modular plants. To date 74 production and reinjection wells have been drilled in the Palinpinon Geothermal Field since 1978 : 57 in the Puhagan, Lagunao, and Ticala-Malaunay sectors and 17 in Nasuji-Sogongon

This study is a compilation of the changes in the apparent piezometric levels of the Palinpinon Geothermal Field as a response to twelve years of operation of the Palinpinon Power Plant, using three periods (1983 or pre-exploitation, 1989, and 1995) as references. Pressure data from some wells were not complete for the periods concerned such that uncertainties are present in the contour maps and cross sections that were generated. The objective of this study is to identify the areas affected and quantify the amount of pressure drawdown as a result of mass withdrawal and reinjection.

The term "apparent piezometric levels" as used in this study are only extrapolated values and may not coincide with the true piezometric levels inside the borehole. The piezometric levels in this paper were obtained by extrapolating the pressures to the depths inside the boreholes where the pressure is 1 bar. Extrapolations for the downhole pressures were mainly based only from the pressure readings taken at the wells' Pressure Control Points (PCP) and at the -1000 m below sea level elevation.. The generated piezometric levels are thus not corrected for the presence of excess enthalpy or gas-rich conditions when the

true piezometric level in the wells may have been depressed. No complete pressure profiles were available when this paper was prepared to offer more precise estimates. This paper shows certain trends in the behavior of the apparent piezometric levels in the field which *may* be studied further and refined when additional data are available.

2.0 REGIONAL SETTING AND HYDROGEOLOGY

2.1 Stratigraphy, Structures, and Permeability Distribution

The Palinpinon Geothermal Field is located on the northern slope of the dormant andesitic Cuernos de Negros Volcano Complex. The field *can* be classified as a volcano-hosted high temperature liquid-dominated system in a steep terrain. **As** a volcano-related field, it **is** underlain by a suite of volcanic, sedimentary, and intrusive rocks ranging in age from Miocene to Recent. These rocks were then intruded by andesite dikes that are related to the latest volcanism event. Table 1 gives a brief summary of the underlying lithologies as taken from Aniceto-Villarosa et al. (1988).

Formation	Age	Lithology
Puhagan Volcaniclastic Formation (PVF)	Early to middle Late Miocene (5.1-24.6 My)	Moderately to intensely altered interbedded andesite lavas, volcanic breccias, and sedimentary rocks.
Nasuji Pluton (NP)	Late Miocene (5.6-10.5 My)	Massive quartz monzo-diorite intrusive, with two events of intrusion .
Okoy Sedimentary Formation (OSF)	Early Pliocene	Fossiliferous calcisiltites, calcarenites, calcareous sedimentary breccia, andesitic volcanic breccia, and minor andesite lavas.
Southern Negros Formation (SNF)	Late Pliocene to Early Pleistocene	Undifferentiated highly altered andesite lavas, hyaloclastites, and volcanic breccias.
Cuernos Volcanics (CV)	Early Pleistocene to Recent (0.0145-0.87 My)	Fresh to weakly altered hornblende two-pyroxene andesite lava, tuff , and volcanic breccia, with minor dacite lavas.

2.2 Fault Structures and Permeability

The Palinpinon Geothermal Field is transected **by** numerous faults (Fig. 2). These faults trend to the northwest and to the north in Nasuji-Sogongon and to the north and **northeast** in Puhagan. **All** of these have been interpreted as normal faults. Field permeability is **mainly** controlled **by** these **fault** structures. Stratigraphic contacts and dike intrusions contribute little to the field permeability except when they are related to any of these faults (Urbino et al., 1986). **An** attempt **has** been made to correlate these faults as intersected **by** the **drillholes** to better understand the permeability in the field (Camit and Villarosa, 1996).

2.3 Hydrothermal Model and Hydrogeology

The hydrothermal model of the field has been established from the field's reservoir and geochemistry data. Amistoso et al. (1993) and Urbino et al. (1988) postulated that the upflow structure for the system lies to the south of Puhagan and southeast of Nasuji-Sogongon with **main** outflow to the northeast towards the Okoy Valley and with a minor northwest **outflow** towards Nasuji-Sogongon. The outflow directions are controlled **by** the faults that transect the area. From the studies conducted **by** Urbino et al. (1988) it has been determined that the reservoir is hottest at a sector south of Puhagan, in an area tapped **by** the wells PN13D, PN20D, PN27D, and OK9D.

Geochemistry predicted reservoir temperatures of **about** 328°C, with pre-exploitation reservoir chloride concentration of 4150 mg/kg. Well PN20D encountered reservoir temperatures of about 329 °C, in agreement with the temperature predicted from geochemistry (Seastres, 1993). Using isotope techniques, Gerardo et al. (1993) identified the composition of the waters that recharge to the reservoir. The result of their studies shows that recharge to the Palinpinon reservoir is **made** up of 80% meteoric water and 20% magmatic components. Based on their calculations, the meteoric water component recharges the reservoir from an elevation of about 1000mASL.

It has been pointed out earlier that permeability in the field is controlled primarily **by** faults. Fig. 3 shows the distribution of the wells' injectivity values. The **different** injectivities of the wells suggest that even the faults and thus the areas they transect have **different** permeabilities. Some sectors in the field show better permeability than others, as in the sectors tapped **by** the wells N3/TC3R, PN31D, and LG4D. These sectors have been transected **by** the Ticala Splay B, Puhagan Splay C, Fault G, and Ticala faults. Based on the Sodium Fluorescein tracer test conducted **by** Urbino et al. (1986) in well OK9RD, some of these faults provide duct flow paths between the reinjection and production sectors. Transit times of between 5.4 - 18.2 days and tracer recovery of 45% has been measured.

3.0 Operation History and Reservoir Response

Seastres (1993) provided a detailed *summary* of the changes in reservoir as a response to exploitation and reinjection. The succeeding paragraphs will cite the major points of his *study*. Production in the Puhagan sector started in June 1983, with an average monthly mass withdrawal rate of 1100-1400($\times 10^3$) tons. Waste water in Puhagan was initially reinjected in the Puhagan reinjection wells, about 500 m north of the Palinpinon-1 Power Plant, from 1983 until 1989. About 70% of the reinjected waters from the Puhagan injection wells return to the production area. A number of production wells (OK7, PN19D, PN26, PN28, PN29D) had experienced cooling as a result. The fault structures Fault G, Puhagan Splay B, Puhagan Splay C, and Ticala Splay B may have provided the channel for the reinjection fluids (see Fig. 2).

Because of severe reinjection returns **from** the **Puhagan** injection pads, some of the waste water was injected into the Ticala-Malaunay reinjection wells, about 2.0 km northeast of the power plant starting in **October, 1989**. Reinjection returns was reduced to 45% when waste injection was shifted towards the Ticala-Malaunay sector, with a number of wells (e. g. PN16D, PN19D, PN23D, and PN29D) recovering their fluid temperatures. Reinjection returns from Ticala-Malaunay were still detected after three months, probably from the well TC3R, with fluids flowing along the Ticala Fault (see Fig. 2). **As** the discharge enthalpies of a number of affected wells (PN14, PN19D, PN29D, PN31D) again started to decline, reinjection into this well was discontinued. In lieu of TC3R, wells PN2RD, PN3RD, and PN5RD (see Fig. 2) in Puhagan were reutilized. This, however, did not prevent the cooling that was experienced. Injection in this sector was still continued due to the decrease in the injection capacities of the Ticala-Malaunay wells.

Injection into TC2RD (see Fig. 2), however, have a much more positive effect. The wells OKIOD and PN13D previously were not utilized due to production of acid fluids. Reinjection fluid from TC2RD flowing along the Odllumon Fault neutralized the fluid acidity resulting in a sustained production of near-neutral pH fluids from these wells. Thermal deterioration due to reinjection returns was not encountered in these wells suggesting that fluid from TC2RD was **sufficiently** reheated as it flows towards the production sector. The Southern Laguna wells (BL1D, LG2D) and wells in Nasuji-Sogongon are not affected **by** reinjection fluid returns from both the Puhagan and Ticala-Malaunay reinjection sectors.

Connection of the neighboring island of Panay to the Negros Power Grid occurred in October, 1990. This necessitated the increase in the production output from the wells and resulted in increasing amounts of waste water for reinjection. The increase in monthly mass withdrawal from about 1400×10^3 to

1890 $\times 10^3$ tons due to the Panay connection, along with reduced reinjection at Puhagan, enhanced the field pressure drawdown in the Puhagan production sector and increased reservoir boiling as shown by the increase in average discharge enthalpies of the production wells. The 80 MWe modular plants in the Nasuji-Sogongon Sector were commissioned in 1994.

4.0 RESULTS AND DISCUSSIONS

Fig. 4 shows the apparent piezometric surface prior to exploitation in 1983. The undisturbed piezometric data shows an updomed feature with peak elevation of 700 mASL in the OK5 area. An updomed feature is also present at OK3R. The lowest undisturbed piezometric level is at 300 mASL located at various places, notably in the N3 and N1 areas. It can also be seen that depressions in the piezometric level are already present even before field exploitation notably in the areas tapped by PN7RD, OK10D/PN13D, and in the Ticala area. Comparing Fig. 3 with Fig. 4 it can be seen that some of these depressions in the piezometric levels corresponds to areas with relatively lower injectivity values. The doming of the piezometric level around OK5 agrees with the postulated upflow near this sector.

The piezometric levels are at depths of 100 m to 400 m below the ground surface in the Puhagan and Ticala areas. Levels in the Nasuji-Sogongon sectors occur much deeper at about 800 to 900 m below the ground surface. At a distance of about 9 km east of Puhagan at well N2 (not covered in the maps), the piezometric level showed artesian characteristics before exploitation. Artesian flow from N2 was recorded to have a head of about 68 m above ground surface at an elevation of 200 mASL (Geotecnica, 1994). This behavior of N2 suggests that the reservoir around the N2 area was a confined aquifer.

Figure 5 shows the apparent piezometric level configuration in 1989. The absence of the dome centered on OK5 is only artificial since pressure data for this well after 1985 is not available. The dome or ridge around the OK3R area is still apparent but at reduced levels. Figure 6, however, shows the difference in levels between 1989 and 1983 based on the other wells. After six years of fluid withdrawal from Puhagan a drawdown of between 20 m in OK10D to 300 m in PN24D, PN5RD, and PN14 were observed. Drawdown in the Puhagan field has an average of 90 m, even though the waste water are disposed of into the Puhagan reinjection wells. This drawdown is greatest in areas tapped by PN15D, PN25D, and PN19D.

Figure 7 shows the piezometric level for 1995. The ridge around OK3R is still apparent. Figure 8 shows the change in apparent piezometric level due to mass drawdown between 1995 and 1989. There has been a general decline in the piezometric level in the Puhagan and the Ticala-Malaunay sectors of the field, with drawdowns of about 50 m in OK8RD to as much as 520 m in PN16D. The average drawdown for the period is about 175 m over the Puhagan area. This is almost two times the average drawdown which occurred between 1983 and 1989. This is most likely due to the increase in mass withdrawal rate as a result of the interconnection with the Panay Power Grid

Figure 9 shows the difference in the piezometric level between 1995 and 1983. There has been a field-wide decline in piezometric level in Puhagan of between 110 m in OK4 to 560 m in PN16D, or an average of 320 m over the whole of Puhagan, as a result of mass withdrawal since the start of operation. Drawdown in the production sector is greatest in the areas near PN25D/PN19D, PN16D/PN23D/PN27D/LG4D. Drawdown in the reinjection sector is largest in PN3RD, with a value of 530 m.

Drawdown near the boundary of the field was also observed. Well N2, the easternmost well that penetrated the geothermal reservoir, previously had an artesian level before field exploitation. After twelve years of fluid withdrawal from the reservoir, the actual measured water level dropped down by as much as 68 m. The present water level is now at ground surface, or at an elevation of 132 mASL (Geotecnica, 1994). After twelve years of production a negative hydrostatic head was developed in the field, with the production sector near the upflow having lower piezometric levels than the surrounding areas. This head reversal also causes reversal in the flow direction between the upflow and the outflow parts of the hydrothermal system. Figures 10a and 10b

shows the hydrologic regime before exploitation and after twelve years, showing the flow directions during the two periods.

The depression of the apparent piezometric level is largest at the Puhagan production sector where mass withdrawal is also greatest. This reversed the hydrostatic head between the production and reinjection sectors, with lower pressures now in the production sector. As a result of **this** reversal in the hydrostatic head between the production and reinjection sectors, the fluids will tend to flow from the edge of the reservoir (at the outflow) towards the center (the upflow). This is a reversal of the pre-exploitation flow regime when fluid tends to flow from the upflow region and down towards the outflow.

Direct hydrologic connection between the production and reinjection sectors are provided **by** faults, some of which have good permeability. The rate of fluid flow between these two sectors depends upon a number of factors. The proximity of the reinjection wells to the **production** sector, the permeability of the connecting faults, and the hydrostatic head determine the rate at which reinjection fluids flow back to the production sector. A rapid return of reinjected fluids back to the production sector can cause reservoir cooling as the hot reservoir rocks were not able to sufficiently heat up the cooler reinjection fluids along its flowpath.

With the reversal **of** the hydrological flow regime where fluid flow is toward the center of the reservoir, further drawdown in the production sector of the field *may* enhance the rate at which reinjection fluids flow back to the center of the reservoir. Areas with rapid injection fluid returns have already been identified. However, the effect of further drawdown on the present flow regime still can not be predicted. Questions such as “Will fluids **from** TC2RD still be sufficiently heated **as** it flows along the Odlumon Fault with further drawdown?” or “At what level and how far away should reinjection be done to minimize its cooling effect?” may be answered with more modelling studies. It is hoped that this *study* was able to identify areas where more work has to be done in order that fluid flow behavior in the Palinpinon reservoir be better understood and its productive life sustained.

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