

THE GEOCHEMICAL RESPONSE OF THE TONGONAN GEOTHERMAL RESERVOIR (PHILIPPINES) AFTER EIGHTEEN YEARS OF PRODUCTION

Danilo B. Dacillo and Farrell L. Siega

PNO-C Energy Development Corporation, Merritt Road, Fort Bonifacio, Metro Manila 1201, Philippines

ABSTRACT

The present geochemical state of the Tongonan reservoir was evaluated to provide an updated hydrogeochemical model of the field. Pressure drawdown plays a major role in the reservoir processes that are continuously observed. The brine recharge to the northwestern part of the field has decreased due to the decline of brine injection load. As a result, several production wells of the northern and central sectors, which have limited recharge from the deep hot source or from peripheral waters, are discharging almost pure dry steam. CO₂ concentrations of the production wells are among the highest in the whole field. To sustain the reservoir, separated brine from the South Sambaloran sector is being injected in the Tongonan-I sector to provide mass recharge to the dry wells. At present, only one production well has shown indications of brine returns. By the end of year 2002, about 270 kg/s of power plant condensate will be injected in the northernmost injection sink which is expected to provide mass recharge to the neighboring production wells. In the northeastern margin of the field, the recharge from meteoric waters has stabilized. The southeastern sector is receiving recharge from injected brine and acid-sulfate waters making it the only remaining water-dominated region of the field.

1.0 INTRODUCTION

The Tongonan geothermal field, found in the island of Leyte, lies along the northwest trending chain of volcanoes parallel to or adjacent to the Philippine fault. It is bounded to the southeast by the cold impermeable Mamban block, which separate it from the Mahanagdong geothermal field (Alvis-Isidro et al., 1993). It is subdivided into three production sectors namely the Upper Mahiao, Tongonan-I and Malitbog-South Sambaloran (Figure 1). Forty-nine production

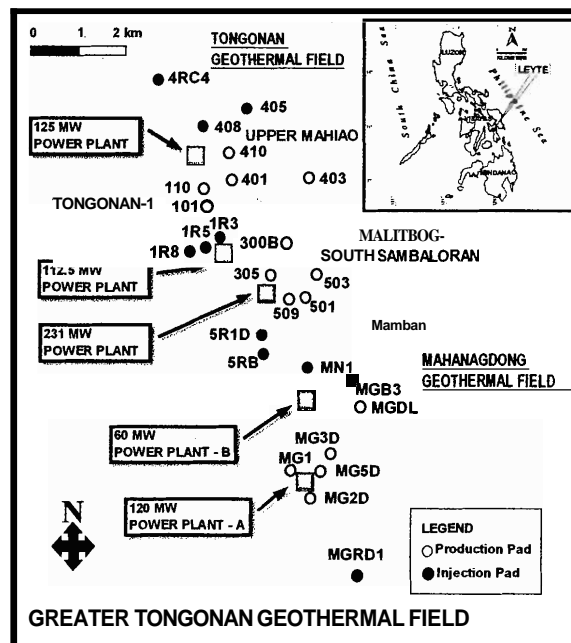


Figure 1. Map of the Greater Tongonan geothermal field showing the two producing fields of Tongonan and Mahanagdong. Inset map shows location of Leyte island in the Philippines. Note: Series 100 and 200 wells belong to Tongonan-1 sector; series 400 to Upper Mahiao sector; series 300 and 500 to Malitbog-South Sambaloran sector.

wells supply the steam requirement of the power plants in the three sectors. Three injection sinks, two in the northern and southern outfield and one infield in the west, receive the separated brine from the production sectors.

Commercial operations started in 1983 with the commissioning of the 112.5 MW power plant in Tongonan-I. In 1996 and 1997, the 125 MW and the 231 MW power plants in Upper Mahiao and Malitbog respectively, were operated. This increased the monthly mass extraction rate from 0.4-1.6 million tons to a peak of 3.5 million tons

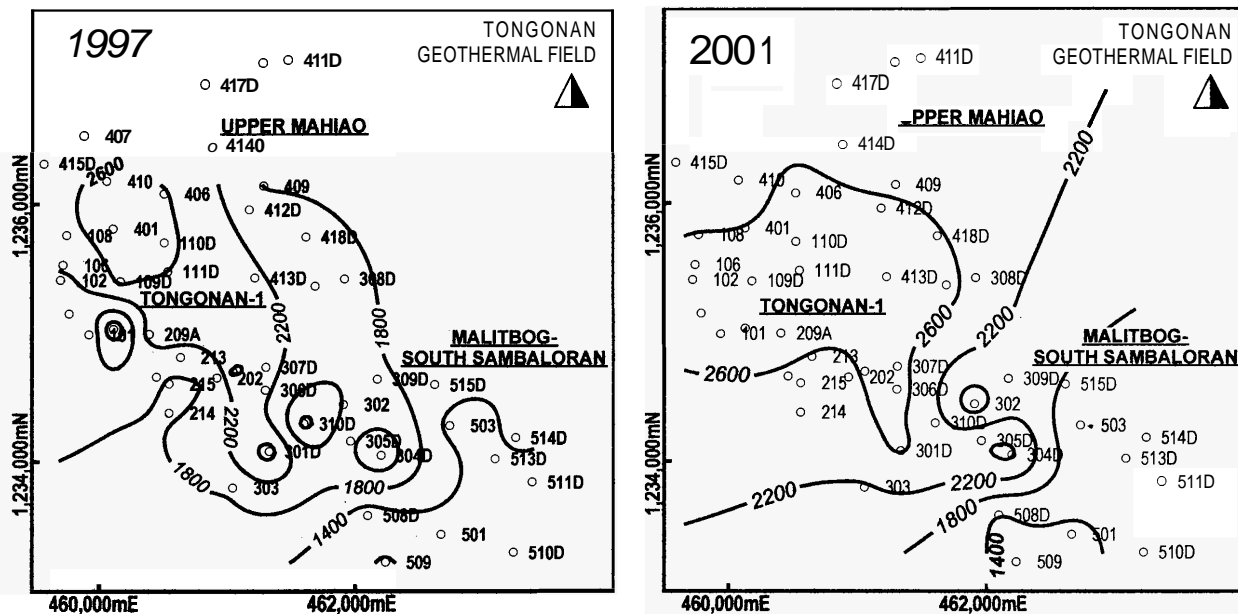


Figure 2. Changes in the contour of discharge enthalpy (in J/g) across the field from 1997 to 2001.

(Salonga and Siega, 1999). About 60% is injected back to the system. In 1998, the 18 MW and 15 MW optimization plants in Tongonan-I and Malitbog respectively, were commissioned.

The massive extraction of fluids, as a consequence of the operations of more power plants, caused major changes in the natural state of the reservoir. Siega et al. (2000) and Maturgo et al. (2001) documented such changes based on water and gas geochemistry tools. Among the observed reservoir processes include the transformation of the reservoir from a liquid to a steam-dominated system due to pressure drawdown. This resulted to a significant increase of reserved steam from each production sector. The decline in reservoir pressure also induced the inflow of peripheral waters such as the brine from the injection sinks of Upper Mahiao and Malitbog, the cooler waters from the northern part of Upper Mahiao and local liquid recharge from Malitbog (Maturgo et al., 2001).

Owing to a large quantity of excess steam in Tongonan field, a steam line interconnection was constructed to address the steam supply deficit in Mahanagdong. This further increased the extraction load of Tongonan by an equivalent of about 50 MW when the interconnection was commissioned in August 2000.

This paper provides an update on the geochemical response of the reservoir to higher rate of extraction for the whole year of 2001. It also presents the geochemical monitoring conducted during the diversion of South Sambaloran separated brine to Tongonan-I, which aimed to provide recharge to the highly steam-dominated sector.

2.0 FIELDWIDE TRENDS

The continuing effect of pressure drawdown in the Tongonan reservoir and the subsequent expansion of the steam zone across the field is manifested in the discharges of the wells. In 1997, the area with highest enthalpy and gas concentration in the discharge was only limited to Tongonan-I production wells. This is because the area has a natural steam cap on top of the upflow region (Salonga, 1997) where most of the gases could accumulate during the first level of boiling. The latest Tracer Flow Tests (TFT) showed that by the middle of 2001, the steam cap has gradually extended up to the South Sambaloran region to the south and a little farther towards the Upper Mahiao in the north. The production wells in this region are already discharging dry steam at enthalpies above 2600 J/g (Figure 2). The same can also be said for the high-gas region in the field. It expanded to the north and south along with the expansion of the shallow steam zone. At present, majority

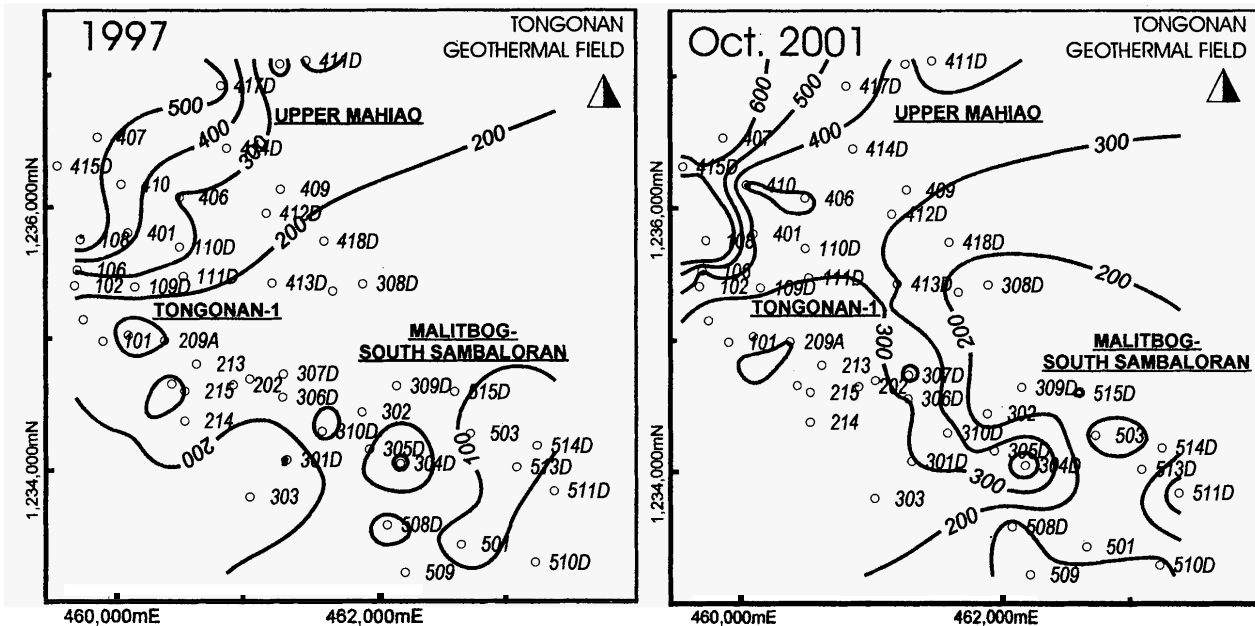


Figure 3. Contours of CO_2 (in $\text{mmol}/100\text{mol}$ steam) in the total discharge of production wells from 1997 to 2001.

of the production wells in South Sambaloran sector has CO_2 concentration above $200 \text{ mmol}/100\text{mol}$ (Figure 3). The only remaining wells that still has substantial liquid component in their discharge, those that have enthalpies below 1800 J/g , are found in the southern section of Malitbog. Their CO_2 concentrations are also among the lowest in the field because of brine returns from the injection sink of Malitbog.

Figure 4 presents the updated hydro-geochemical flow model of the Tongonan reservoir based on the most recent data on enthalpy and geochemical trends of production wells. The dry steam cap in Tongonan-1 now reaches a depth of around 900m below sea level. This is based on downhole surveys in well 101 which showed absence of water level from top to bottom. The discharge of the well is already pure steam at an enthalpy above 2700 J/g .

The expansion of this cap towards South Sambaloran is displayed by well 303, whose permeable zones are relatively clear of any blockages. The discharge enthalpy of well 303 in 1997 is 1800 kJ/kg which increased to 2100 kJ/kg in 1999. Well 302 also showed an increase in enthalpy from 1240 kJ/kg in August 1998 to 1440 kJ/kg in April 2001. However, well 302 is deeper and has more permeable zones in

the bottom that tap the liquid region, so its discharge enthalpy is lower compared to well 303.

The steam cap is tapering up towards the outflow in the north since production wells in Upper Mahiao, that still has minor inflow of cooler waters and injected fluids, have enthalpies ranging from 2000 to 2600 J/g . In Malitbog-South Sambaloran sector, this is deduced from the data on well 509. The well's discharge enthalpy is 1307 J/g indicating a dominantly liquid feed. Its bottom permeable zones are practically blocked by obstructions at 1319mMD and 1520mMD tagged by a $6''$ and $3''$ Go-Devil tools, respectively (Figure 4). The only remaining feed zone at the top, which would have been a two-phase region, is predominantly liquid and is therefore a flow path of the injection returns in this area.

3.0 SECONDARY RESERVOIR PROCESSES

3.1 Inflow of Cooler Fluids in Upper Mahiao Sector

In 1999, cooler waters were observed to be moving from the northern periphery of Upper Mahiao towards well 409. The fluids were further characterized as less saline and relatively degassed based on the gradual decline of Cl_{res}

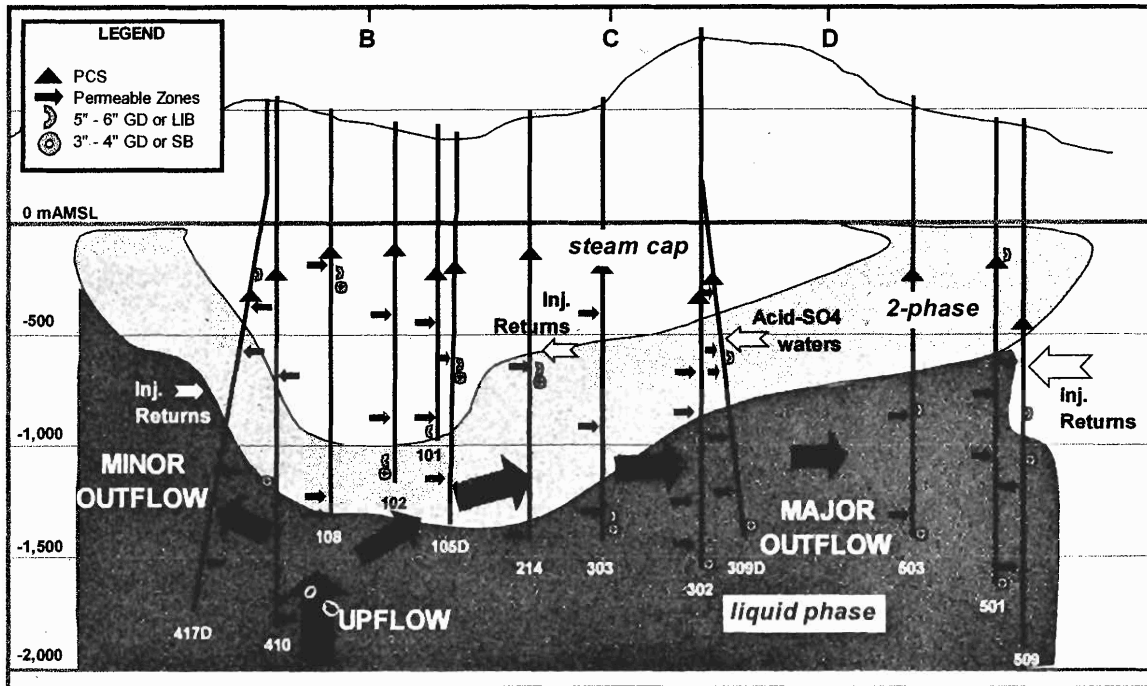


Figure 4. Present hydrogeochemical flow model of Tongonan geothermal reservoir.

and CO₂ of well 409 (Maturgo, 2001). The well's waterflow gradually increased from 18 kg/s in April 1998 to 22 kg/s in June 1999 with a corresponding decline in enthalpy from 2110 J/g to 1990 J/g.

Downhole measurements indicated that these cooler waters pass through the permeable zone at 1900 mMD. Based on the hydrogeochemical model before the commissioning of Upper Mahiao and Malitbog power plants, the cooler waters would be coming from the vicinity of wells 411D and 416D (Salonga et al., 1997). Structural correlation indicates that these fluids are channeled through the Balabag Fault that was intersected by well 409 and other wells with thermal inversion in the northern margin of Upper Mahiao.

Pressure drawdown in Upper Mahiao is progressing as reflected by the continuing decline of the separated brine from this sector (Figure 5). Despite this, the influx of cooler dilute fluids into well 409 has not increased. This is evidenced by the stable trend of the reservoir chloride of well 409 at around 7500 mg/kg. The enthalpy and CO₂ content of the discharge likewise remained relatively stable at around 2000 J/g and 300 mmol/100mol, respectively (Figure 6). These trends suggest that the cold

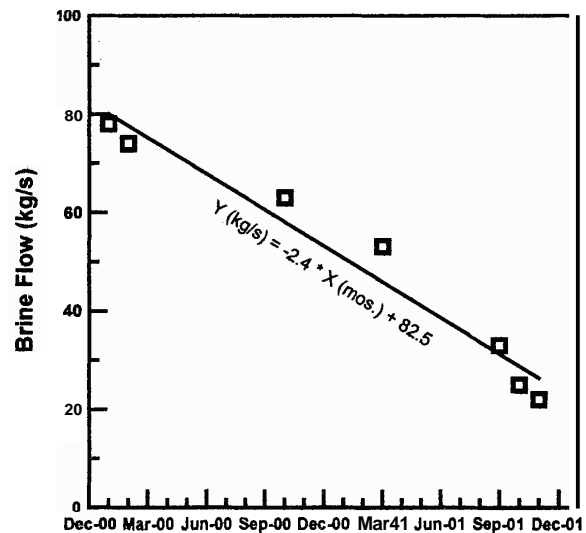


Figure 5. Historical trend of the measured brine flow of Upper Mahiao.

aquifer is relatively small or the additional influx may have just been boiled off by the dry reservoir before reaching well 409. This is also implied in the trend of the waterflow which declined back to 18.9 kg/s (May 2001 TFT) from 22 kg/s in June 1999. The present continuing decline of reservoir temperature based on quartz (T-Quartz) is already attributed to decline in reservoir pressure and not on cold water inflow.

3.2 Decline in Injection Returns in Upper Mahiao Sector

Physical and chemical trends have shown the persistence of injection returns in well 410 until the year-end of 2000. However, chemical and TFT data for the year 2001 showed indications of decline in brine returns into the area of well 410 in the southwestern section of Upper Mahiao.

The CO₂ content in the discharge of well 410 increased from 42-166 mM/100M in year 2000 to 255-282 mM/100M in year 2001 indicating 'declining influx of highly-degassed brine. Physical data also showed decrease in waterflow of the well from an average of 16 kg/s in year 1999 and 2000 to 8 kg/s in year 2001 while enthalpy increased from 1900 kJ/kg to 2200 kJ/kg.

The decline of brine returns in this area of the field is attributed to the decline of brine disposed into the injection wells of pad 408 situated northeast of well 410. Measurements of Upper Mahiao brine load registered a flow of 78 kg/s in January 2000 which gradually decreased to 22 kg/s in November 2001 (Figure 6).

3.3 Brine Injection Returns in Malitbog-South Sambaloran Sector

For the year 2001, the incursion of brine coming from the injection sink of Malitbog towards neighboring production wells persists. Wells 501, 509, 510D and 511D, found in the southern part of Malitbog exhibited continuous increase in reservoir chloride concentration with corresponding decline in CO₂-content which are tell-tale signs of injection returns.

The trends are clearer in the crossplot of CO_{2TD} and Cl_{res} in Figure 7. It is apparent from the shift of data points of wells 501, 509 and 511D that the encroaching fluids influencing their chemistry are the separated brine from Malitbog.

The data points of well 510D are more shifted towards the present chemistry of 501 instead of the separated brine from Malitbog. This suggests that the highly saline and degassed injected brine have swamped the two wells and therefore their uniform chemistry.

For well 509, the likely source is 5R1D based on positive tracer returns in 1996 (Parilla et al.,

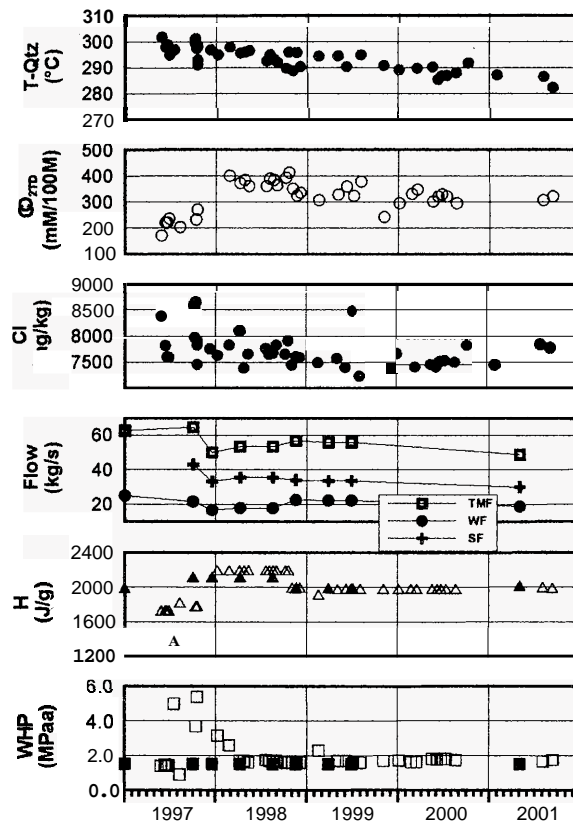


Figure 6. Physical and geochemical trends of well 409.

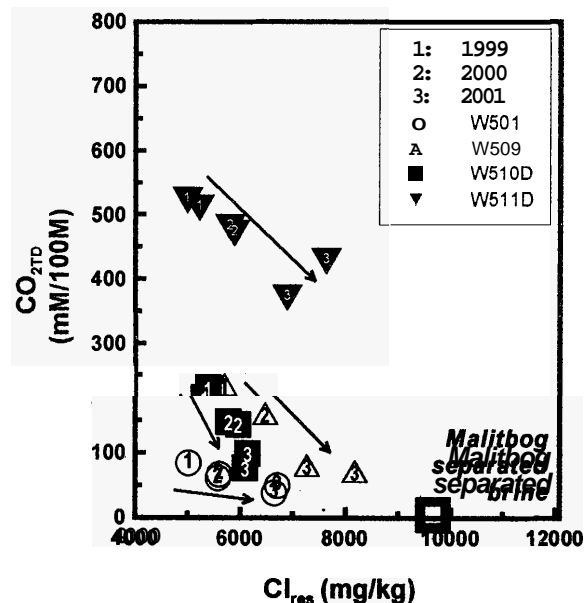


Figure 7. CO₂ and Cl_{res} cross plot of Malitbog wells with injection returns.

1996) which indicated that the contact between Mamban formation and Mahiao Sedimentary Complex provided the hydrological connection.

3.4 Inflow of Acid-SO₄ Waters

The northern part of Malitbog and a section of South Sambaloran are continuously experiencing inflow of cooler, dilute waters. This is based on the geochemical and physical changes observed in three production wells – 309D, 503 and 515D – drilled in the said area.

The above wells have been showing continuous gradual decline in reservoir temperature and chloride. The enthalpies of 309D and 515D, likewise declined from 2100 kJ/kg and stabilized at 1800 kJ/kg (Figure 8). In the same figure, the chloride concentration and enthalpy of 309D has converged with that of 515D at around 9000 mg/kg and 1800 kJ/kg, respectively, starting in the year 2000. This means that the cooler waters has already reached the center of the South Sambaloran sector from the eastern part of Malitbog.

In Figure 6, there are indications that the cooler fluids are SO₄-rich and acidic. Wells 309D and 515D are showing gradual increase in SO₄ while in well 503, the inflow of cooler fluids may have equilibrated as evidenced by stabilization of SO₄ after an initial increase. Well 515D is also showing a drop in pH from 6.0 in year 2000 to 5.5 in year 2001. The other two wells have pH levels stable at 6.0 although there were fluctuations to lower pH observed in year 1999 and 2000.

These types of fluids may have originated from the northeastern part of Malitbog. Two unproductive wells from this area, 505D and 516D, have higher sulfate concentrations and lower pH relative to the production wells of Malitbog and South Sambaloran. During their discharge in 1981 to 1984, the SO_{4res} of the two wells ranged between 40 to 100 mg/kg whereas other Malitbog and South Sambaloran wells, which were discharged during the same period, had less than 50 mg/kg (Figure 9). Furthermore, the pH of 516D is relatively lower at 4.0-6.5 (weber and atmospheric pH) compared to the others which had near-neutral pH of 6.5 to 8.0.

The occurrence of a possible acidic aquifer in Malitbog is supported by a study made by Scott (2001). According to him, acid alterations are most abundant in, and adjacent to, veins in the eastern (Malitbog) sector of the Tongonan field. Acid-altered minerals found include pyrophyllite, diaspore, kaolinite, anhydrite and lesser quartz,

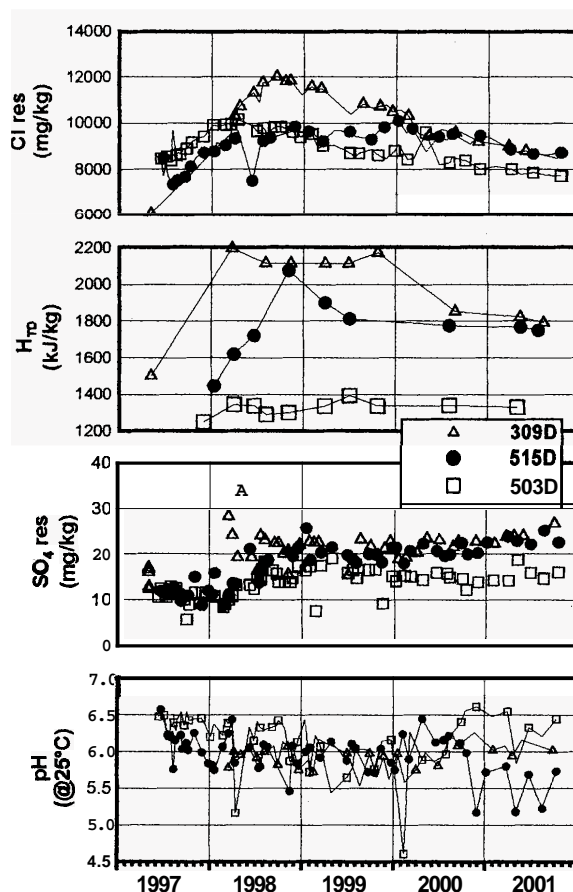


Figure 8. Geochemical trends of Malitbog-South Sambaloran wells with acid-SO₄ water inflow.

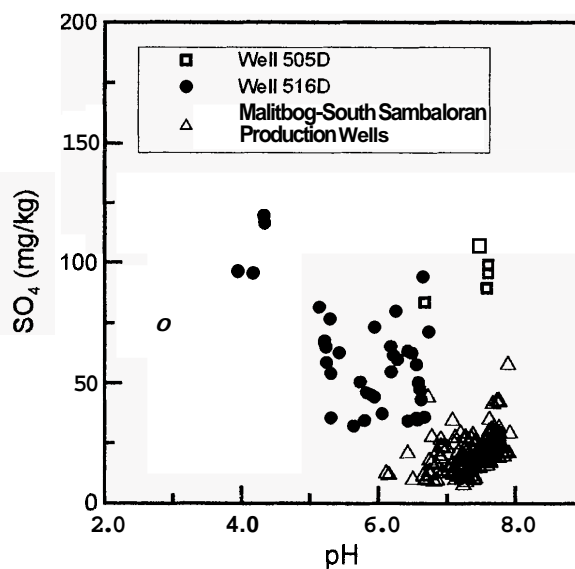


Figure 9. Comparison of pH and SO₄ content of Malitbog-South Sambaloran wells.

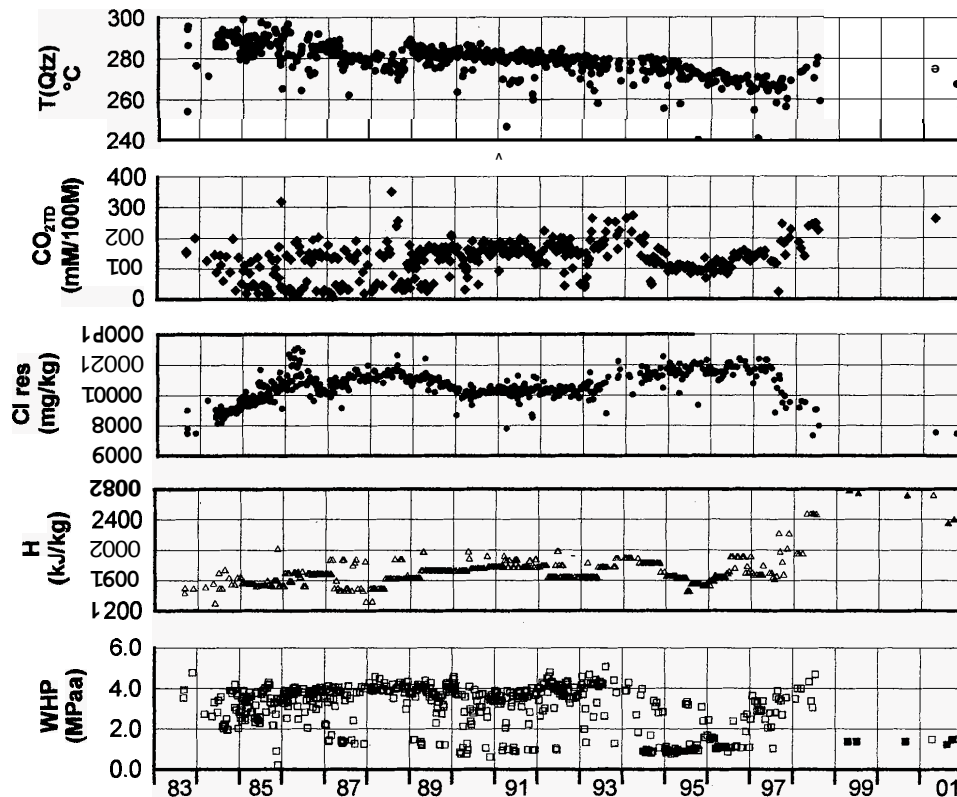


Figure 10. Physical and geochemical trends of well 215.

pyrite, sphalerite, calcite, illite, alunite and hematite. It was not clear though if these acid alterations are relict or not.

3.5 Fluid Recharge to the Dry Sectors

Brine from the South Sambaloran was previously disposed to the injection wells of pad 4RC4. Starting September 2000, the brine was partially and intermittently diverted to Tongonan-1 to provide recharge to the 'dry' wells of this sector. Full load diversion of brine started only in August 2001.

So far, only well 215 has shown prominent signature of injections returns based on chemical and physical data. The well has been discharging dry steam with an enthalpy above 2400 kJ/kg since year 1998 up to year 2000 due to fieldwide pressure drawdown. Its reservoir chloride concentration was dropping and could be assumed to be practically zero during the time when its enthalpy was already around 2700 kJ/kg (Figure 10) since it was already tapping the steam cap of the reservoir. During this year, however, physical data indicate inflow

of liquid recharge. The well's measured waterflow in August 2000 was 1.2 kg/s which increased to 7.0 kg/s by August and October 2001. Enthalpy declined from 2700 kJ/kg to 2360-2400 kJ/kg during the same period.

Evidence of brine recharge is also suggested by the resurgence of high-chloride concentration ($Cl_{res} > 6000$ mg/kg) in its reservoir. The reservoir temperature based on $T(\text{Quartz})$, as well as the CO_2 -content in the well's discharge, declined gradually which consistently indicate the inflow of cooler, degassed injected brine. Tracer tests in February 1980 and April 1981 have established that the structural connection in this area is through the Sambaloran and Urangon faults.

Since the latest enthalpy data is still above the baseline level of 1600 kJ/kg and that the thermal impact based on $T(\text{Quartz})$ is still not so significant, the brine inflow is still considered beneficial at present as mass recharge to Tongonan-1 production wells. Redistribution of brine load, however, may be necessary in the future when the cooler injection returns become

detrimental to the production wells. Further monitoring is needed to fully evaluate the impact and the extent of area that will be recharged since full brine diversion happened only in August 2001.

The dry wells of Upper Mahiao may also soon receive recharge from pad 4RC4. The condensate from the power plant will be injected to the northwesternmost sink by the end of year 2002 when the PNOC-EDC will implement the zero waste disposal scheme. The power plant condensate will supplement the declining brine recharge from pad 408.

4.0 CONCLUDING REMARKS

The Tongonan geothermal field has been in operation for eighteen years. The continuous mass extraction across the whole field caused changes in the reservoir that are being observed since the commissioning of additional power plants and the steamline interconnection.

The declining brine flow of Upper Mahiao indicates that the sector has limited amount of recharge and that it is becoming drier. The injection of power plant condensate to pad 4RC4 comes at the right time when the dry sector needs adequate recharge to sustain the field. If the recharge will not be attained, partial or full load injection in pads 408 or 405, which are nearer to the reservoir, should be considered. The thermal impact of such strategy can be minimized through optimum loading of injection wells.

In Malitbog-South Sambaloran, the movement of peripheral waters (i.e. injection returns and acid-sulfate waters) towards the production sector is seen as beneficial in providing pressure support to the system. However, the recharge from the injected fluids is more preferred since acid-sulfate waters has the potential to initiate anhydrite (CaSO_4) deposition aside from the possible corrosion problem associated with lower pH waters. In Tongonan-I, the diversion of South Sambaloran brine towards this sector is already providing mass recharge to neighboring areas.

REFERENCES

- Alvis-Isidro, R.R., Solafia, R.S., D'Amore, F., and Gonfiantini, R. (1993). Hydrology of the Greater Tongonan geothermal system, Philippines as deduced from geochemical and isotopic data. *Geothermics* 22, 435-449.
- Maturgo, O.O., Siega, F.L. and Salonga, N.D. (2001). Geochemical monitoring of the reservoir-wide pressure drawdown in the Tongonan geothermal field, Leyte, Philippines. *Proceedings, 22nd Annual PNOC-EDC Geothermal Conference*, 1-8.
- Parilla, E.V., Bolaños, G.T. and Herras, E.B. (1996). Impact of 5R1D reinjection to the Bao-Banat-I Springs. PNOC-EDC internal report.
- Salonga, N.D., Alincastre, R.S., and Auman, R.O. (1997). The geochemical model of Tongonan geothermal field prior to full commissioning of 450 MWe power plants. *Proceedings, 18th Annual PNOC-EDC Geothermal Conference*, 172-181.
- Salonga, N.D. and Siega, F.L. (1999). Evaluating the expansion and sustainability of the upper steam zone in the Tongonan geothermal field (Philippines) using gas chemistry. *Geothermal Resources Council Transactions* 23, 399-403.
- Siega, F.L., Martinez-Oliver, M.M. and Salonga, N.D. (2000). When liquid-dominated reservoir turned vapor-dominated: the sixteen-year production history of Tongonan geothermal field, Philippines. *Proceedings, 21st Annual PNOC-EDC Geothermal Conference*, 1-8.
- Scott, G.L. (2001). Hydrothermal alteration and fluid geochemistry of the Tongonan geothermal field, Philippines. *Resource Geology*. 51, 117-134.