

Response of Bao-Banat-i Thermal Areas to Commercial
Operations in Tongonan Geothermal Field, Leyte, Philippines from 1983 to 1996

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Abstract

The chemical trends of the Bao-Banat-i hot springs are reviewed to resolve whether these springs are the outflow of the Tongonan or Mahanagdong geothermal systems and to study the response of these springs to Tongonan I commercial operations. Mineralization of the Bao-Banat-i springs had shown declining trends from their pre-exploitation values with the onset of commercial operations in Tongonan I in 1983. This trend is attributed to the effect of decreasing reservoir pressures leading to a reduction in contribution of outflowing deep reservoir fluids to the surface discharges. However, there was no indication of reinjection fluid returns from the Tongonan I sector to Bao-Banat-i springs based on decreasing chloride from 3000-3500 mg/kg in 1981-1982 to 1983-1989 levels of 1000-2000 mg/kg. Moreover, Cl/B ratio was maintained for most of the springs, at baseline levels of 30-35. The observed decline in Cl/B for some of the springs is due to increasing contribution of groundwaters, which have Cl/B ratio of 5-10.

Tracer test using Iodine-131 in 5R1D, which was conducted on December 1982-January 1983 yielded negative results in the Bao-Banat-i springs. This was conducted while 5R1D was having reinjection load of 65 kg/s from Well 509. However, an increase in spring flow rates was noted when the load to 5R1D was increased to 164 kg/s in January to September of 1983; the flow rate subsequently declined when the reinjection well was shut. The recent utilization of 5R1D for the pre-commissioning activities of the 77 Mwe Malitbog Power Plant again reflected an increase in mass discharges of the Bao-Banat-i springs and thermal activities in the area. Moreover, this is paralleled by increase in the chloride level of the hot springs and by the positive returns of Na-Flourescein tracer to the monitored springs, concluding that the Bao-Banat-i is an outflow of Tongonan and that the springs respond only to 5R1D injection at high RI load (>140 kg/s).

1.0 INTRODUCTION

The Bao-Banat-i thermal area is considered to be the most impressive of the thermal manifestations in the Greater Tongonan Geothermal Field found in Leyte. The thermal area consists of the most number of hot springs, fumaroles and steaming vents producing the highest levels of water and steam discharges. It is also the only thermal area discharging neutral-pH chloride waters with a high degree of mineralization suggesting direct contribution from deep geothermal fluids. Owing to these features, the Bao-Banat-i thermal area had become the main thrust of extensive monitoring started in 1983. The other thermal areas include the Kapakuhan, Mahiao, Paril, Hanipolong, Mamban and Mahanagdong, all of which, discharge acid sulfate waters.

According to a report by Abiog in 1969, the chemistry of the Tongonan thermal springs was first determined by workers of the Bureau of Mines in 1965. This was followed by surveys conducted prior to exploration by the Commission on Volcanology and by the New Zealand Department of Science and Industrial Research during the exploratory stages of development. Based on the data gathered during the said surveys, an assessment on the response of the thermal springs, during the six years of drilling and discharge testing, was done by Cope, Lovelock and Baltazar in 1982. Their findings indicated no significant changes in the thermal springs chemistry. A more intensive quarterly monitoring program was soon started in 1983 to provide valuable information on the changes occurring in the deep reservoir as a consequence of field exploitation, particularly the commercial operation of Tongonan 1 in 1983, and to provide necessary data

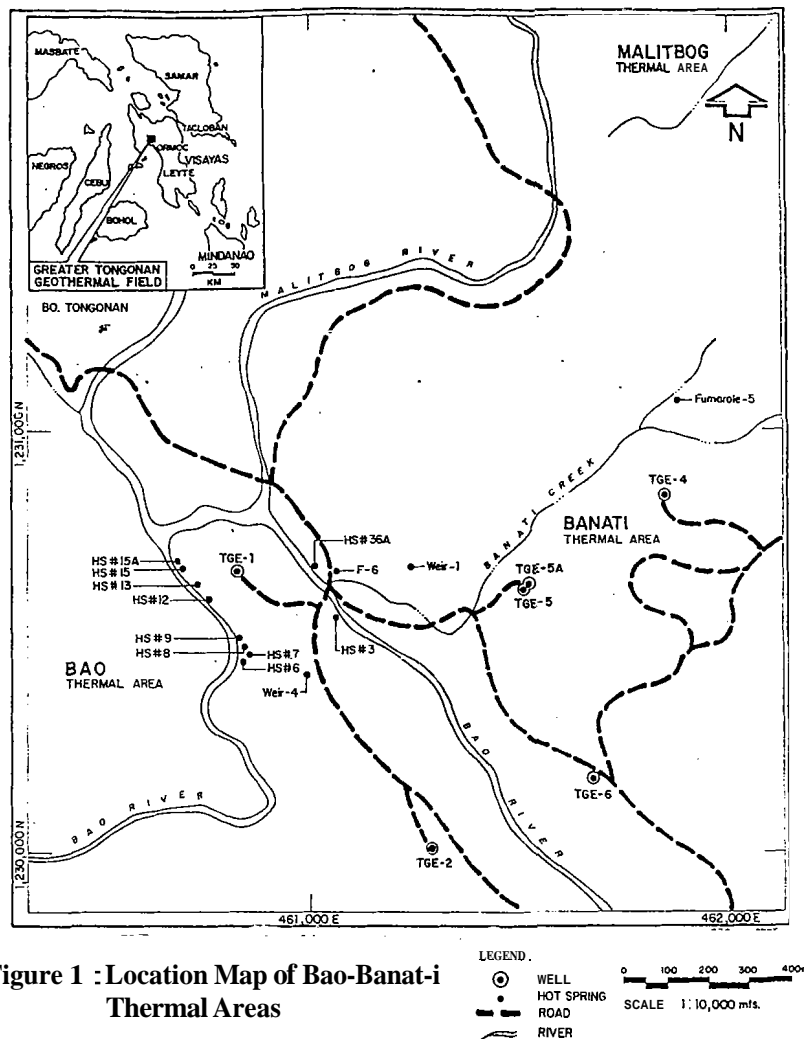


Figure 1 : Location Map of Bao-Banat-i Thermal Areas

needed in giving reservoir assessment and simulation studies for the Tongonan geothermal field. The frequency was later reduced to bi-annual monitoring in 1985, for *dry* and wet season, when no significant changes were observed in the chemistry of the hot springs during the given time interval. This paper aims to present the impact of the last 13 years of commercial operations in Tongonan I on the physical and chemical changes observed in the Bao-Banat-i thermal manifestations.

2.0 DESCRIPTION OF THE BAO-BANAT-I SPRINGS

2.1 Physical Features

The Bao-Banat-i thermal area is located southeast of the Tongonan Geothermal field at an elevation of 220 m ASL (Fig.1). It encompasses the largest number of hot springs among the thermal areas in Greater Tongonan. Numerous **springs** could be found along the Bao river and the Banat-i creek. Fumaroles and steaming vents could be found near the confluence of the Bao-Malitbog rivers. The thermal area contains 18 of the 37 **hot springs** and 4 of the 9 fumaroles originally included in the 1984 monitoring program, the rest are scattered in the other thermal **areas** of Tongonan.

In the early 1970's, the thermal activity in the area has been described to be highly impressive owing to widespread geysering and steaming activities and to the existence of several prominent features which include hot spring #1 found in the vicinity of the Banat-i creek, hot spring #4 near Bo. Tongonan and hot spring #36 located on the left bank of the Bao river (Salonga, et.al., 1996). Hot spring #1 is more popularly known as "orasan", which means clock in the local vernacular, due to its periodic geysering activity. Hot spring #4 was noted to have one of the highest massflows among the Bao-Banat-i springs at 20.0 kg/s.

The declining thermal activity in the Bao-Banat-1 thermal area had become a trend since Tongonan I operated in 1983. However, an exception was observed in December 1982-January 1983, coinciding with the utilization of 5R1D for reinjection at a low load of 65.0 kg/s. A noticeable increase in mass discharge of the Bao-Banat-i springs was observed. This change occurred again in May-August 1996, coinciding with the reinjection in 5R1D during the pre-commissioning activities in Malitbog, but at a higher load of 224 kg/s. It was observed that there is an increase in the activity of the hot springs as exemplified by the increase in the measured mass flow of hot springs #1, #7, and #8. Hot spring #3 located in the bank of the Bao river displayed more frequent and vigorous geysering during the height of reinjection in Malitbog, as documented in a 24 hour monitoring conducted on 01 June 1996 (Parrilla et al., 1996). Moreover, hot springs #4 and #36 re-appeared during the height of reinjection after drying up in 1985. Both features disappeared after reinjection activities in Malitbog halted.

3.2 Chloride Trends

The baseline chloride levels (Fig.3) of the Bao-Banat-i springs in 1981-1982 indicated high degree of mineralization at 2500-3500 mg/kg comparable to the chemistry of shallow geothermal wells TGE-4, TGE-5 and TGE-5A at 2900-3700 mg/kg. Chloride levels of the springs steadily decline from 1983 to 1989 to a low of 500-1500 mg/kg, which is correlated to the declining reservoir pressures as a consequence of massive mass extraction from the reservoir thus, effectively reducing contributions emanating from the deep geothermal fluids. However within the middle period of 1990-1995, a temporary increase of chloride level was observed. This was attributed to the utilization of 1R8D for Mahiao brine reinjection (Salonga et al., 1996). However, it again declined in 1995. The decline in the chloride levels of the hot spring suggests the absence of reinjection fluid breakthrough coming from the Mahiao-Sambaloran reinjection fluids with chloride levels in the range of 12500-16000 mg/kg. However, a notable increase in the chloride levels of the hot springs was observed in May-August 1996, coinciding with reinjection activities at 5R1D at the rate of 140-220 kg/s, during the pre-commissioning activities in Malitbog. This trend suggests the Occurrence of a reinjection breakthrough from 5R1D to the Bao-Banat-i springs.

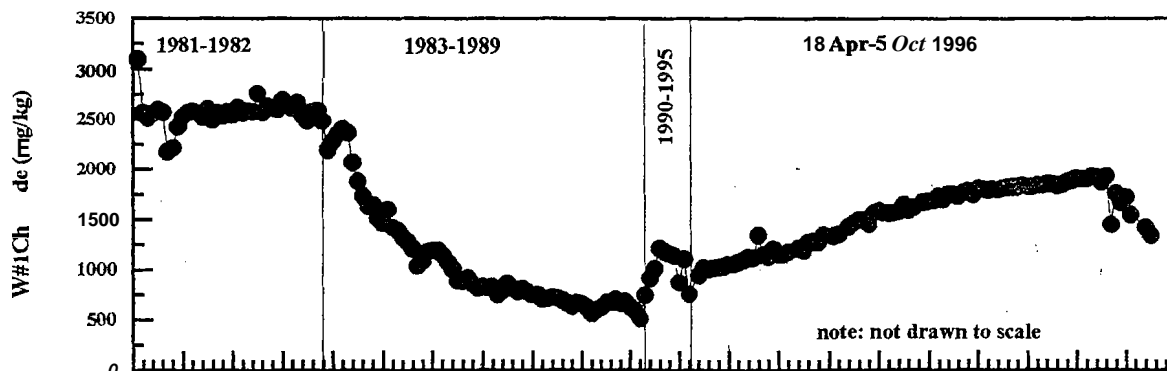


Figure 3 : Trend in Chloride of Spring #1 with Time

3.3 Cl/B Trends

The Cl/B ratio of the reinjection brine range from 13-18 while the Bao-Banat-i Cl/B ratio ranged from 29-35. Theoretically, the Cl/B ratio is expected to approach the reinjection brine ratio in the event of a breakthrough of reinjection waters from Mahiao-Sambaloran, that is, assuming reinjection fluids would not undergo changes/secondary processes on their way to the surface. While Cl/B ratio was maintained for some springs, a decline was observed in the Cl/B ratio of other hot springs, starting in 1983-1995, particularly hot spring #1 (Fig.4). The decline could not be due to reinjection breakthrough from Mahiao-Sambaloran, but rather due to the increasing contribution of groundwaters with low Cl/B ratio of 5-10. This is a consequence of the decline in reservoir pressures, which reduces contribution of deep geothermal fluids, and effectively increasing the groundwater component of the springs discharges. The slight increase in Cl/B of the hot springs in May-August 1996 indicate a general tendency of the springs to approach their original Cl/B ratio. The steep increase in the chloride levels of the springs is not matched by a corresponding steep increase in boron, thus

effectively increasing the ratio. **This** trend is due to partitioning of boron during boiling or the fixation to clays as fluids rise to the surface.

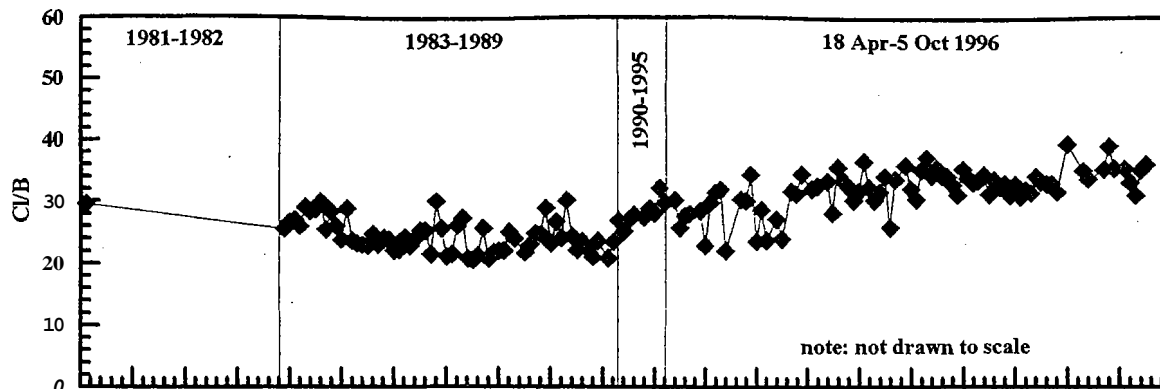
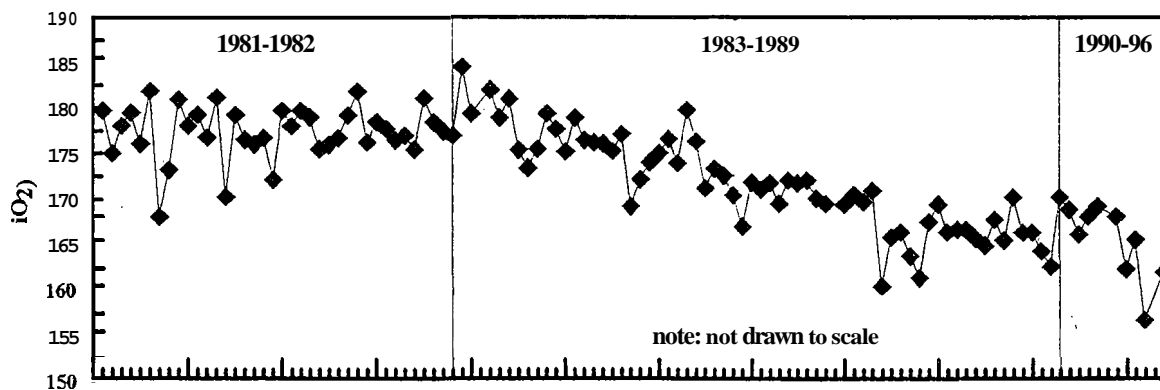


Figure 4 : Trend in Cl/B of Spring #1 with Time

3.4 T(SiO₂) trends

Corresponding to the decline of chloride and massflow levels of the Bao-Banat-i springs, a decline in the temperatures based on T(SiO₂) was observed. This is due to decline in silica concentration because of decreased contributions from deep geothermal fluids and by the increased dilution by shallow ground waters. This trend is most exemplified by hot spring #1 (Fig.5).



The positive results of the Na-Flourescein tracer test, and the observed chemical trends, confirm the earlier speculations of a reinjection breakthrough between 5R1D fluids and the Bao-Banat-i springs. The negative results of 1-131 tracer in 1982 is now believed to be due to low reinjection load. At the time of 1-131 tracer injection, the load of 65 kg/s is insufficient to induce a breakthrough. If it was only done at a later time, when reinjection load increased to 164 kg/s in January-September 1983, positive returns could have been observed.

5.0 CONCLUSION

The commercial operation of Tongonan I induced depression of reservoir pressures, due to massive mass extraction effectively decreasing the contribution of deep geothermal fluids to the Bao-Banat-i thermal springs. This is reflected by the following trends:

- The observed decline of flowrates in the hot springs, as well as, the demise or reduction to non-flowing pools of several Bao-Banat-i springs.
- The declining trends in the springs mineralization.
- The observed slight decline in the Cl/B ratio of the springs as a consequence of decreasing contribution of deep geothermal fluids and the increasing dilution by groundwater.
- The declining trend in T(SiO₂) indicating less component of deep geothermal fluids

The temporary resurgence of thermal activity in the area in December 1982 to September 1983 as well as in May-August 1996, is correlated to the impact of reinjection activities, particularly the use of 5R1D, in Malitbog sector. The impact of reinjection in 5R1D is most pronounced at high reinjection load (>160 kg/s). The communication of reinjection fluids coming from 5R1D caused the observed increase in mineralization and increased thermal activity in the Bao-Banat-i area. This communication had now been confirmed by Na-Flourescein tracer test.

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