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The Bacon-Manito Surface Thermal Features – Geochemical and Physical Changes After Three Decades (1983-2013) of Monitoring

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ABSTRACT

Surface thermal manifestations are important features of almost all geothermal fields in the world. During production stage, the effect of mass extraction and injection can be observed from these surface thermal features.

The Bacon-Manito geothermal field (BacMan), located in Albay, Philippines, is related to the Pocdol volcanic complex and has been of geothermal interest since exploration activities started as early as 1979. Power production, however, only started in 1993 when the first power plant, BacMan-1, was commissioned. The baseline physical and chemical characteristics of thermal areas in BacMan were compared with their characteristics after three decades of exploitation to determine the effects, if any, of continuous production.

Results indicate that exploitation of the BacMan geothermal field did not have a significant effect on the chemical characteristics of the selected thermal springs, except for a single spring, which showed a continuous decrease in chloride. This indicates that this spring may have connection with the current resource. Physical characteristics of surface thermal features, such as water flow rate and surface temperature have remained generally unaffected, indicating pressure support and preserved high subsurface temperatures.

The minimal effect on surface thermal manifestations in BacMan indicates that the current strategies implemented are capable of sustainable exploitation.

1. INTRODUCTION

The Bacon-Manito Geothermal Field (BacMan) is found within a northwest-trending belt of volcanoes in the Bicol provinces of southern Luzon. Two active volcanoes, Mayon and Bulusan, and another geothermal production field (Tiwi geothermal field) are found along this chain. The site comprises an area of about 300km^2 covering the Manito Township and the Municipality of Sorsogon. There are about fifty (50) thermal manifestations in the area which include fumarolic activity in Mt. Pangas, boiling hot springs, mud pools, and high flow cold springs. The geographic location, elevation, and fluid types of these springs conform to the typical geothermal systems found in the Philippines and are consistent with andesitic hosted volcano systems – steam-heated acid-sulfate springs are located at high elevations, while chloride and bicarbonate rich springs are found at intermediate to lower elevations.

Full geothermal exploration by PNOC-EDC started in September 1977, which included geological, geochemical and geophysical surveys that employed shallow resistivity surveys. Almost two decades later, in September 1993, after exploration drilling and further surface exploration, commercial operation started when the first 55-MWe turbine of the BacMan-1 power plant was commissioned (Tolentino, et. al. 2004). Before commercial operations started, a compilation of baseline data from early exploration works was prepared as reference to future review of the effects of exploitation to the geothermal system. This report will try to show the effects, if there are any, of continuous exploitation to the physical and chemical features of surface thermal manifestations in BacMan.

2. CHEMISTRY OF SURFACE THERMAL WATERS

2.1. Baseline Chemistry

The BacMan field thermal manifestations include about fifty (50) springs distributed over an area of 300 km^2. These thermal features range from fumarolic activity and steaming altered grounds in Mt. Pangas (790mASL); bubbling mud pools in Malangto, boiling hot springs in Naghaso and Parong (0-5mASL) to high-flowing cold springs in Damoy (5mASL). The location and altitude of these springs conform to the model by Harper and Arevalo (1982) for systems that occur at high relief regions, i.e. steam-heated acid-sulfate springs are located at high elevations while bicarbonate and chloride springs are found at intermediate to lower elevations.

To determine the effects of exploitation, the baseline fluid chemistry of springs and wells from early exploration in 1980 to the commissioning of BacMan-1 in 1993 was compiled. Baseline fluid chemistry suggests that there are at least five (5) fluid types present in BacMan as indicated by the relative concentrations of Cl, SO_4 and HCO_3 (Figure 1). Classified as Cl springs are the Buang (BU), Naghaso (NH), Osiao (OS), Parong (PR) and Pawa (PW) springs found at elevations of 0-10 mASL; SO_4-rich

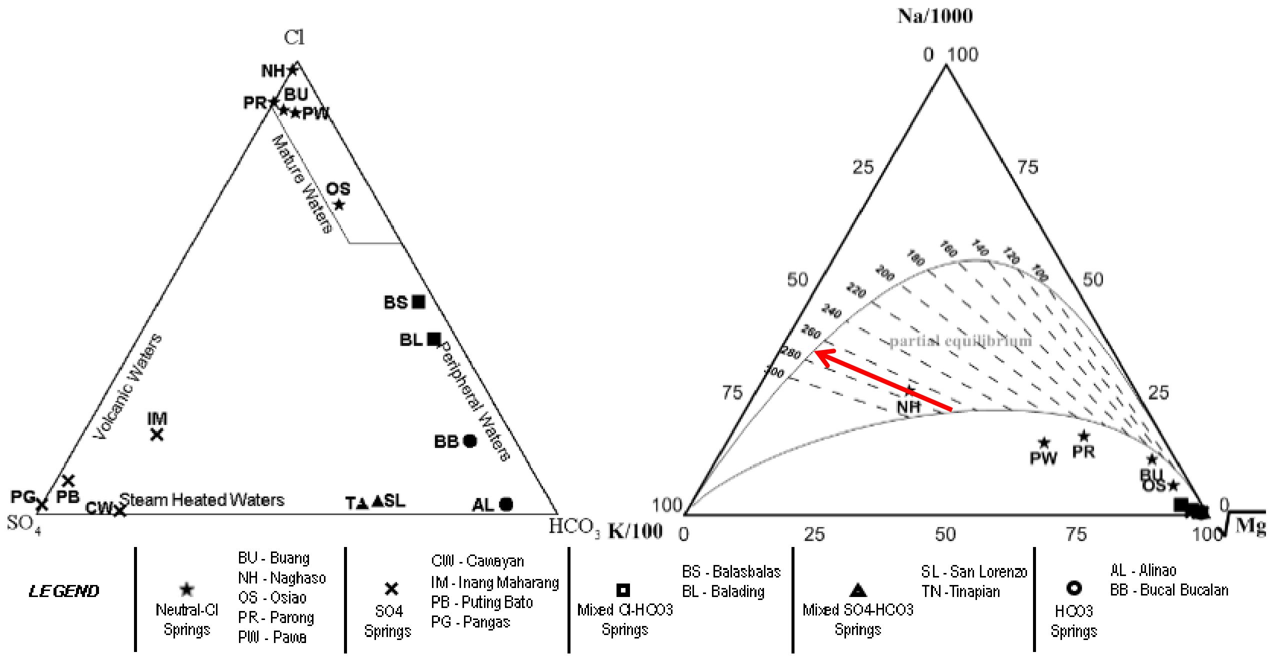

Figure 1 (left) Cl-SO_4-HCO_3 plot of surface thermal manifestations in BacMan showing five (5) fluid types (right) Na-K-Mg ternary diagram indicating partial equilibrium of Naghaso (NH) waters and estimated subsurface temperature of ~270°C.

waters are the Cawayan (CW), Inang Maharang (IM), Puting Bato (PB) and Pangas (PG) springs located at elevations above 250 mASL; mixed Cl-HCO_3 waters are the Balasbalas (BS) and Balading (BL) springs; mixed SO_4-HCO_3 waters are the San Lorenzo (SL) and Tinapian (TN) springs located at elevations of 10-425 mASL; and HCO_3 waters are the Alinao (AL) and Bucal-bucalan (BB) springs located at elevations of 275 and 0mASL, respectively.

The Na-K-Mg diagram shows the extent of equilibrium of fluids with the surrounding rocks. Among the Cl springs of BacMan, only Naghaso plots within the partially equilibrated region of the diagram. Use of geochemical tools using the Naghaso spring waters give the most reliable results since these have significant geothermal input (Cl) and equilibrated with rocks.

Silica and cation geothermometers estimate a minimum reservoir temperature of 184°C (T_{SiO2}) and maximum of 271°C (T_{NaK}). Measured field temperatures at -1000mRSL in the vicinity of the upflow, however, average 270°C min and 300°C max which suggest that secondary processes, probably mixing with groundwater, causes the reservoir temperature to be underestimated. Nevertheless, the temperatures derived from silica and cations indicated during exploration a promising geothermal resource in BacMan.

2.2. Three decades of monitoring of surface thermal manifestations

The response of the reservoir from continued development and exploitation of the field can be observed from surface emanations present in the field. After more than a decade of surface exploration and drilling activities, power production started in 1993 when the first power plant, the 110MWe BacMan-1, was commissioned. Since then, a bi-annual chemistry monitoring program was established to determine the effect of exploitation on the chemical and physical characteristics of springs in BacMan. Five (5) out of the fifty (50) springs in BacMan were chosen for monitoring based on their chemical characteristics, e.g. Cl springs (Buang, Naghaso, Parong, Pawa), and accessibility and with massive physical features (Inang Maharang). Physical characteristics of the selected springs are shown in Table 1, while their locations are shown in Figure 2.

Table 1 Physical characteristics of selected thermal manifestations for monitoring in BacMan

Spring	Physical manifestation	Temperature	pH	Deposits/Alterations
Buang	Warm spring	43°C	6-8	No deposits/alterations
Inang Maharang	Steaming grounds, bubbling pools and mud pools	97°C	5-8	No deposits/ heavily altered clays are widespread across the thermal area
Naghaso	Hot spring	87-96°C	3-6	No deposits/alterations
Parong	Bubbling pool	59-104°C	5-7	No deposits/alterations
Pawa	Hot spring	51-92°C	6-8	Yellow-orange deposits/ no alterations

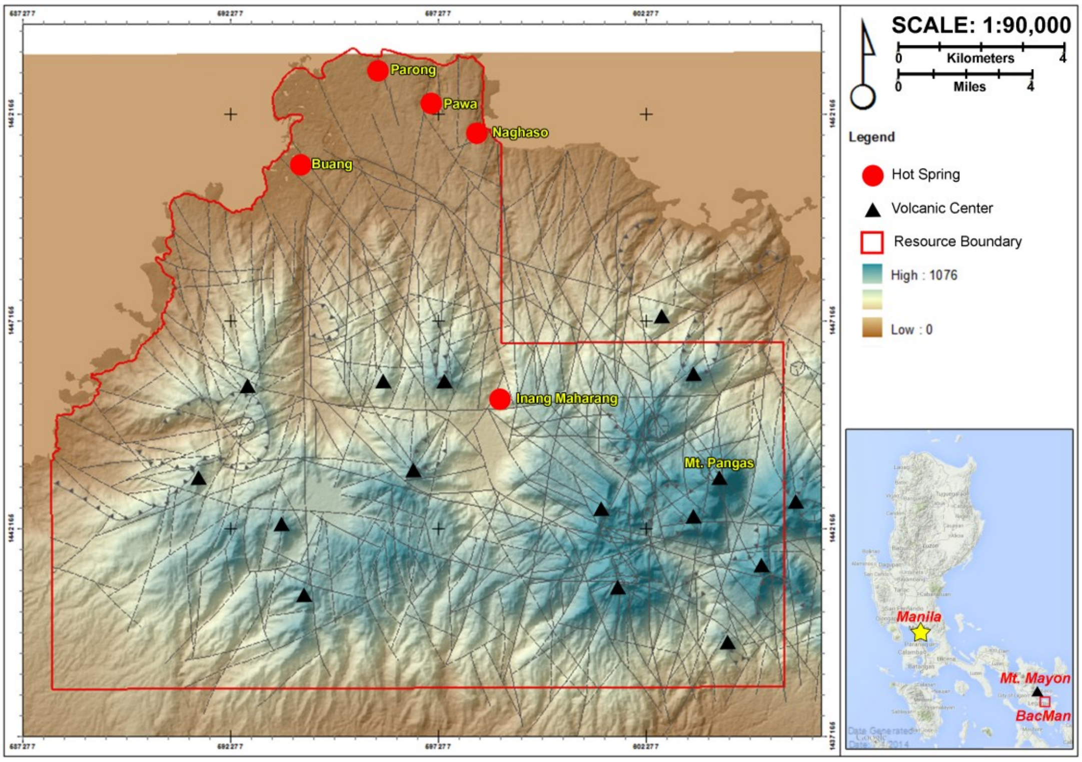

Figure 2 Location map of selected thermal manifestations for bi-annual chemistry monitoring

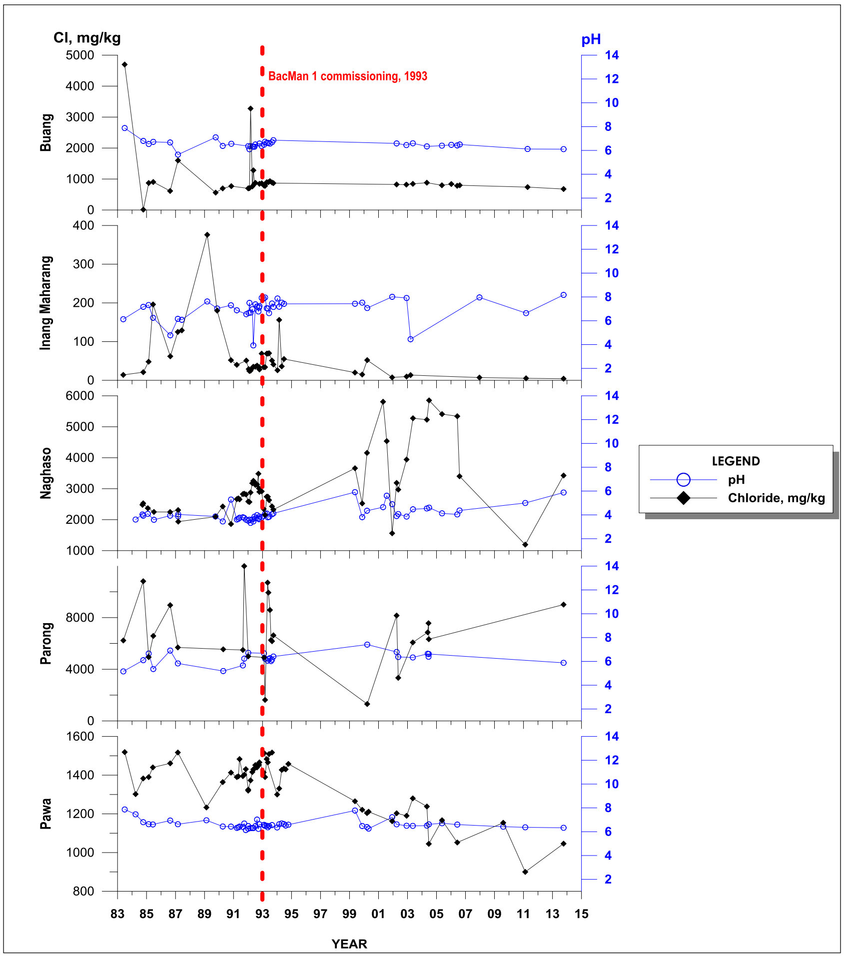

Figure 3: Cl and pH trends of selected surface thermal manifestations from 1983 through 2013.

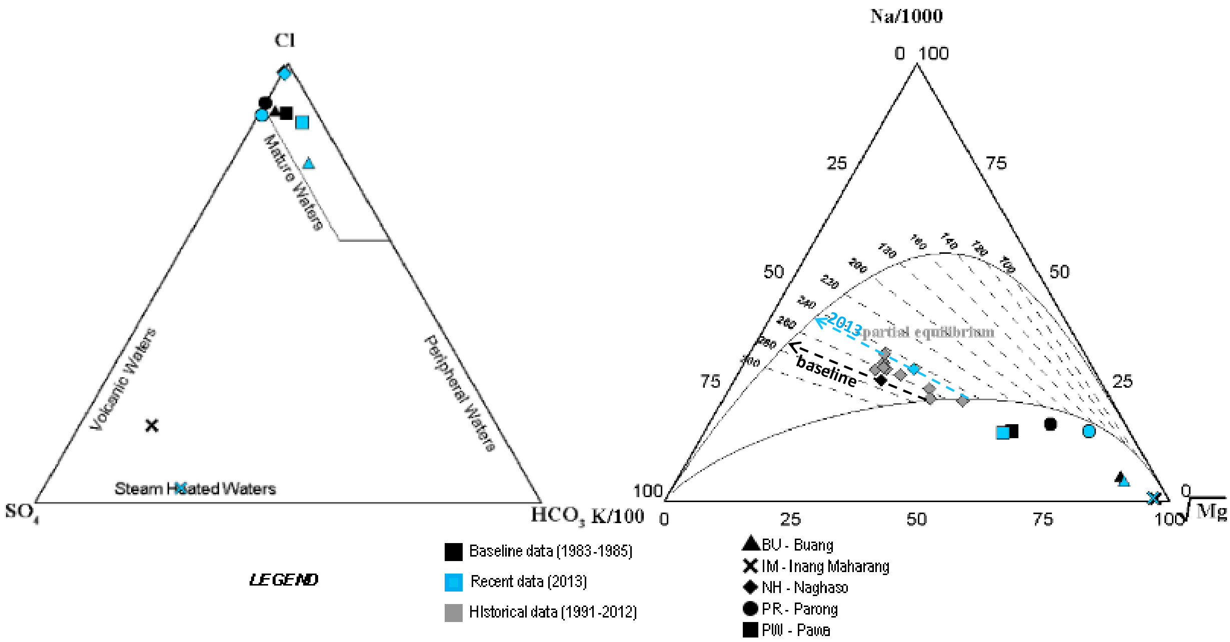

Figure 4: Cl-SO_4-HCO_3 (left) and Na-K-Mg (right) ternary diagrams comparing baseline (1983-1985; black) and 2013 (blue) chemistry of selected thermal manifestations. Naghaso data from 1991-2012 are shown as grey diamonds.

Figure 3 shows the trends in Cl and pH of the selected springs from 1983 through 2013. The Buang spring Cl and pH trends showed unsteady behavior from 1983 to 1993, and then stabilized after 1993. Inang Maharang, trends were also unstable before 1993. There were sudden and massive increases in Cl concentrations which increased the Cl content of the spring up to ~400mg/kg before 1993. The sudden spikes in Cl did not recur after 1993, and Cl continually decreased to its present value of <10mg/kg. The pH in this spring remained at near neutral to neutral levels all throughout the study period. Unlike the Buang and Inang Maharang springs, the Cl and pH trends of the Naghaso spring were already stable before 1993, but showed erratic behavior after the commissioning. From a relatively stable Cl concentration of ~2,500mg/kg pre-commissioning, Cl concentrations spiked up to ~6,000mg/kg and dropped down to ~1,100mg/kg post-commissioning. Fluctuations in Cl may be due to periodic influx of seawater due to its relatively low elevation (5mASL). The pH of Naghaso spring, however, is relatively stable at acidic to near neutral levels. The Parong spring, found at an intertidal location, is frequently contaminated with seawater. This explains the frequent spikes in Cl throughout the study period. The pH of this spring is also relatively stable at near neutral levels. Among the springs being monitored, the Pawa spring may have the most direct connection to the currently exploited resource. This can be seen in the Cl trend showing a continuous decrease in Cl concentration since the commissioning of the power plant in 1993. From initial Cl levels of ~1,200 to ~1,500mg/kg, it dropped to 900 to ~1,100mg/kg levels in two decades. The pH however, remained at near-neutral levels during the study period.

Figure 4 shows a comparison of the fluid types derived from relative Cl-SO_4-HCO_3 of the baseline and 2013 chemistry of the selected springs. It shows that the springs of Buang, Naghaso, Parong, and Pawa remained to be Cl-rich waters. Meanwhile, the Inang Maharang spring showed a shift towards the SO_4 apex of the diagram, indicating increased in SO_4 uptake. This is expected, to a certain extent, from a steam-heated spring whose SO_4 content is directly proportional to the amount of upflowing gas.

The Na-K-Mg diagram (Figure 3) also shows very minimal change the Na, K, and Mg ions in Buang, Inang Maharang, and Pawa springs, while the springs of Naghaso and Parong show a slight shift towards the Mg apex. Both springs are located at proximal distance to surface waters (lake and seawater), which might have caused the slight shift towards the Mg apex. However, Naghaso spring chemistry still plots within the near equilibrium area which suggests that the relative composition of Na, K, and Mg still conforms to the temperature dependent reaction equilibria (Giggenbach, 1991)

$$\text{K-feldspar} + Na^+ = \text{Na-feldspar} + K^+ \tag{1}$$

and

$$2.8\ \text{K-feldspar} + 1.6\ \text{water} + Mg^{2+} = 0.8\ \text{K-mica} + 0.2\ \text{chlorite} + 5.4\ \text{silica} + 2\ K^+ \tag{2}$$

Therefore the drop in estimated subsurface temperature from the baseline (~270°C), to ~250°C in 2013 (20°C drop) is not mainly due to contamination with meteoric water, but rather a consequence of continuous exploitation of the resource. This is confirmed by the actual measured temperatures at -1000mRSL, which shows a slight decrease in temperature from the average baseline measured values of 270-300°C to an average of 250-260°C in 2012 (Alvarado, P.B., et al., 2012) . It is important to note, however, that the measured decrease in subsurface temperature occurred over a period of 20 years and could be attributed to inflow of cooler fluids.

There are very minimal changes in chemistry of the selected springs in BacMan and if there were any, they could be explained by meteorological factors (Parong springs) and the nature of the springs (steam-heated Inang Maharang spring). However, the Naghaso spring chemistry suggests that there might be a decrease in subsurface temperature as indicated by the Na-K-Mg ternary diagram.

3. CHANGES IN PHYSICAL CHARACTERISTICS OF THERMAL MANIFESTATIONS

Physical manifestations of geothermal systems such as fumaroles and steaming grounds are one of first to disappear when there is massive unsustainable exploitation. Several such manifestations in BacMan have undergone changes since the early stages of exploration.

3.1 Pangas Fumarole

The most notable change in physical characteristic among the BacMan thermal manifestations was the disappearance of the fumarole in the summit of Mt. Pangas. Located at 850mASL, the fumarole discharged hot gases (75°C) at relatively low flow rates, suggesting subsurface condensation. However, since 1990, fumarolic activity in Pangas has ceased. This was even before the BacMan I power plant was commissioned (1993), suggesting that commercial operations did not contribute to the disappearance of the fumaroles.

3.2 Parong Hot Spring

The Parong hot springs are located at a sea-submerged location. Noticeable geysering activity and massive upwelling were observed from this spring during the first exploration stages. However, in 1992, or even earlier, these physical manifestations have vanished (geysering) or decreased (massive upwelling). The local inhabitants in the area claim that during Mt. Mayon's eruptions, the geysering activities and upwelling decrease significantly (See, 2000)

3.3 Naghaso Hot Spring

A "breathing" feature, i.e. sudden surge of water every 2 minutes, was observed from this spring during the early sampling periods (See, 2000). However, this characteristic has since disappeared since October 1994 and could be attributed to the exploitation of the resource since it disappeared after the BacMan I power plant was commissioned. However, locals also claim that when Mt. Mayon erupts, the water level of the lake near the spring (Lake Naghaso) recedes.

4. CONCLUSIONS

Physical and chemical characteristics of selected surface thermal manifestations have continuously been monitored since 1993 when the commercial operations in BacMan started. Selection of these thermal manifestations was based on chemistry (Cl rich) and occurrence of massive features. Fluid chemistry of the Buang, Inang Maharang, and Parong springs do not indicate a direct correlation with the ongoing exploitation in BacMan and infrequent fluctuations are mainly caused by meteorological effects like seawater influx or mixing with groundwaters. The Naghaso spring chemistry, however, suggests a drop in subsurface temperature based on the Na-K-Mg ternary diagram, which is confirmed by downhole temperature readings. On the other hand, the decreasing Cl concentration of the Pawa spring since 1993 suggests that it is affected by the ongoing exploitation. Cl concentrations of Pawa decreased from a value ranging from ~1,200 to ~1,500mg/kg to its current range of ~900 to ~1,100mg/kg.

Impressive physical features of some thermal manifestations like Pangas, Parong and Naghaso have also vanished since early exploration stages. The disappearance of the manifestations, however, cannot be associated to the ongoing exploitation since they occurred even before the commissioning and start of commercial operations in 1993. Locals also suggest that some of the manifestations (Naghaso and Parong) are related to the volcanic activity of Mt. Mayon.

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