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THE GEOCHEMISTRY OF THE MT. BALUT ISLAND GEOTHERMAL PROSPECT, DAVAO DEL SUR, PHILIPPINES

Cecilia Polo Balmes[1]
[1]Geothermal Division-Energy Resource Development Bureau, Department of Energy, Energy Center, Merritt Road
Fort Bonifacio, Taguig, Metro Manila

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ABSTRACT

The acidic waters of Mt. Balut Island precludes the use of cation geothermometry for the calculation of its reservoir temperature. Instead, the silica mixing plot was used to predict the subsurface temperature, assuming that a chloride-rich reservoir exists. In the absence of a suitable cold water sample from the area, an assumption was made that the composition of surface waters, in terms of SiO_2 concentration, is similar. Based on eleven cold water samples from different provinces in the Philippines, an average SiO_2 concentration of 33 ppm was obtained. This, together with the SiO_2 concentration of the warm waters in Mt. Balut were plotted against the corresponding enthalpy equivalent of the measured water temperatures.

The silica-enthalpy mixing model shows that it is possible that a reservoir with a temperature of 196°C exists. Hydrologically, the chloride-rich water could be submerged under the sea. But how do we prove this and do we have the technology to tap such resources? In the meantime, we can only surmise that the geothermal resource in Mt. Balut Island can only be used for domestic as well as recreational purposes.

1. INTRODUCTION

The implementation of the project, "National Inventory of Geothermal Resources" in 1997 brought one of the survey teams of the Geothermal Division to the southeasternmost tip of the Philippine archipelago, the Mt. Balut Island, that is politically a part of the province of Davao del Sur. In this far-flung island, pirates are feared to rove the waters, sowing apprehensions to visitors, but which seasoned travelers and residents are fast to disprove.

Amidst these apprehensions, the survey team, composed of Ruel T. Malapitan, Antonio de Guzman from the Mindanao Field Office and the author, braved the seas on board the public ferry which leaves the pier at General Santos City at about midnight and reaches the island at dawn.

Indeed, the trip was uneventful, the passengers just spent a restful night, lulled by the sleep-inducing waves.

1.1 Geologic Setting

Mt. Balut Island, an emergent submarine volcano is located south of Mindanao Island or north of the Molucca Sea Region (MSR) which includes Mindanao, northern Sulawesi, Halmahera and the arc systems (Figure 1). It is the earth's only example where collision between two facing volcanic arcs (Sangihe and Halmahera) occurs (Morrice, 1983; Malapitan, 1997). It is also the site where back-arc thrusting occurs along the Cotabato and Philippine trenches and the volcanic centers are inactive and dissected (Salonga, 1992, Malapitan, 1997).

Balut Island belongs to the Central Physiographic Province consisting of sub-provinces of Babuyan, Cagayan-Caraballo, Central Luzon, Bondoc-Sarangani, Central Visayas and Cotabato (GOP, 1982; Malapitan, 1997). The geo-tectono affiliation of Mt. Balut Island is closely related to the Mindanao Central Cordillera of the Bondoc-Sarangani Subprovince. Mindanao Central Cordillera extends north-south for about 400 km. from Mt. Hibok-Hibok in Camiguin to Sangihe Ridge which includes prominent volcanic edifices such as Mts. Apo, Parker, Matutum and Balut. It is bounded on the east by Pacific Cordillera and Agusan-Davao Lowlands; on the west by Lanao-Bukidnon Highlands, Cotabato Valley and Daguma Range (GOP, 1982; Malapitan, 1997).

The island is characterized by central peaks aligned in a NE-SW direction with elevations ranging from 702 m.a.s.l. to 863 m.a.s.l. The eastern side of the island is characterized by rolling to undulating grounds, whereas, the western side is generally rugged to steeply sloping towards the summit. Conical and dome structures are common along the shoreline dotting the southwestern and southeastern ends of the island. These bulges could be former fissure vents during the volcano's early history (Malapitan, 1997).

Regional geologic structures follow a northwest trend. These are expressed by the trend of the faults (e.g. Mindanao fault) and the Cotabato trench and likewise manifested by the fold axes in the sediments, as well as the topographic highs such as Daguma range and the Tiruray High. Drainage lines such as Malambako, Sasapoan, Tinina have NW-SE trends suggesting a structurally controlled river system (Salonga, 1992).

Rock exposures in the area consist of lava flows, pyroclastics and recent deposits which include sand, gravels, boulders and corals fringing the coastline (Malapitan, 1997).

2. THERMAL MANIFESTATIONS AND WATER TYPE

Thermal manifestations were found in four barangays in the island (Figure 2). These are warm to hot waters with temperatures that range from 38-75°C. A solfatara area was found in Barangay Takol. The waters from Brgy. Lipol are the hottest and the most acidic (field pH = 2) while those from Brgys. Tinina and Bato Ganding are warm with neutral to near neutral pH. The chloride levels of the waters are low, ranging from 123-279 ppm; HCO_3 range from nil to 606 ppm while sulfate levels range from 26-564 ppm. It is shown in

Table 1 that higher temperature waters have higher chloride and sulfate levels than the warm waters, which in turn are bicarbonate rich.

As to the cationic content of the waters, it is apparent that the magnesium concentrations that range from 21-54 ppm are high. This could be due to rock dissolution or mixing.

For easy referencing, the waters will be referred to in this report as Lipol, Bato Ganding and Tinina waters, indicative of the barangays where the waters were collected.

2.1 Lipol waters

The occurrence of hot water emanations in Brgy. Lipol was noted in Sitio Sabang and Tambulos. That from Sitio Sabang is located along the shoreline as a pool of about 8 m in diameter (DVS-05w). The water has a temperature of 75°C. It is clear, bluish green in color and for this reason, the survey team named the manifestation as the "Emerald Pool". Several bubbling centers were noted on the pool and steam engulf the vicinity. As is usual in acidic manifestations (pH=2), soft, altered ground surround the pool. In Sitio Tambulos, just a few meters walk from Emerald Pool is another pool of water measuring about 5 m long, 2 m wide and 1.5 m deep. The water is turbid, has a pH of 2 and a temperature of 66°C. A faint H_2S odor pervades the area. No sample was taken from this area since the water is stagnant but this manifestation is indicated in the sample map as DVS-07w.

Just a few meters from this pool and towards the sea, bleached boulders of andesitic rocks are abundant. These are manifestations of the occurrence of acidic water beneath. Water sample DVS-08w was collected by digging through the sand beneath the boulders. The water has a temperature of 74°C and as with the two previous manifestations, the pH is 2. It is possible that this water has the same source as DVS-05w and DVS-07w. In the Schoeller diagram in Figure 3, DVS-05w and DVS-08w plot as samples with the highest sulfate values. Consequently, the waters were classified as of the *Na-SO_4* type.

2.2 Bato Ganding waters

The sample DVS-06w is being hosted by pyroclastic rocks. The 38°C water flows through a plastic pipe at a rate of 1L/5sec into a pool of cold water. The pool of cold water is probably a mixture of the thermal and river water. However, there were no suitable sites to sample the baseline as well as the mixed waters. Residents immerse themselves on the pool, using the water for bathing, clothes washing and other domestic purposes.

DVS-06w is a *Na-HCO_3* type water and has a pH of 6. In Figure 3, it has a bicarbonate level which is lower than that of the seawater sample (DVS-09w) but higher than all the other samples.

2.3 Tinina waters

Sample DVS-10w is located on the shores of Sitio Pandaring at Brgy. Tinina. As with DVS-08w, the sample was obtained by digging through the gravels and sand on the shore. The water has a temperature of 39°C and a pH of 6. On the Schoeller diagram, this shows up as the sample with the highest bicarbonate level.

2.4 Takol Solfatara

The area is characterized by very dry, intensely altered ground and patches of native sulfur deposits. The area is within a probable collapsed structure. Moreover, according to local folks, it was previously mined for native sulfur by TEXCO, a Canadian Mining Company which they believed was really into treasure hunting (Malapitan, 1997).

3. RESERVOIR TEMPERATURE

Based on the chemistry of the samples, conventional cation geothermometers may not be applicable for the calculation of the subsurface temperature of the Mt. Balut waters. The Na-SO_4 Lipol waters are acidic, and therefore cations could be products of the leaching of the country rocks by the waters as they ascend to the surface.

The Bato Ganding and Tinina waters, on the other hand, are Na-HCO_3, warm, and probably dilute waters. On the Cl-HCO_3-SO_4 diagram in Figure 4, these waters plot along the Cl-HCO_3 axis, on the peripheral water region. For this type of water, the cation geothermometers cannot be applied with confidence. In this case where no chloride waters are available, the silica-enthalpy-mixing model is resorted to obtain an estimate of the reservoir temperature. While the high magnesium content of the acidic waters could be attributed to leaching of the country rocks, the high magnesium in the warm, neutral waters (DVS-06w and DVS-10w) could have been obtained from mixing with a high-magnesium containing cold groundwater at shallow levels. The waters could not have been contaminated with seawater, as evidenced by the low chloride content of the thermal waters.

Since the survey team was not able to collect a suitable cold water sample aside from the seawater, an assumption was made that the composition of surface waters, in terms of SiO_2 concentration is similar. From eleven samples gathered from different provinces in the Philippines, SiO_2 concentration ranges from 30-39 ppm or an average of 33 ppm (Table 2).

The average SiO_2 content was plotted against the enthalpy equivalent to 29°C, the temperature of the seawater as measured during the survey. The silica composition of the warm waters was plotted against the enthalpy equivalent of the field temperatures (Figure 5). It is assumed here that the water has boiled and lost steam before mixing with the cold waters. Based on this plot, a reservoir temperature estimate of 196°C was obtained. From this diagram, it is inferred that the parent fluid has an original silica concentration of 249 ppm.

4. GEOCHEMICAL MODEL

For this system, although no true chloride spring was found (it might be submerged beneath the sea), it is assumed that a chloride-rich water exists in the deep reservoir. This water has an estimated subsurface temperature of 196°C, based on the silica-enthalpy-mixing model. As this water rises to the surface, it encountered sulfur deposits. The oxidation of sulfides and maybe thiosulfides gave rise to acidic waters that manifest in Brgy. Lipol. On the other hand, boiling might have occurred, producing steam that exudes at the surface as steaming manifestations called the Takol solfatara, the site of occurrence representing the upflow zone. Where the waters traveled a longer route, mixing took place at much higher intensity. The resulting waters manifested as the warm waters in Brgy. Tinina and Bato Ganding.

5. CONCLUSION AND RECOMMENDATIONS

The silica-enthalpy mixing model was constructed to aid in the estimation of the reservoir temperature. Theoretically, we assume that true chloride springs exist, but these could be submerged beneath the sea, following the usual hydrological model of a geothermal system in an island-arc setting. The problem is, how do we prove that high-chloride hot springs do exist? More so, do we have the technology to tap the heat from submerged springs? Until these barriers are overcome, the geothermal energy potential of the Mt. Balut Island, as with that of Camiguin in Mindanao, would not be utilized except for direct uses such as for domestic and recreational purposes.

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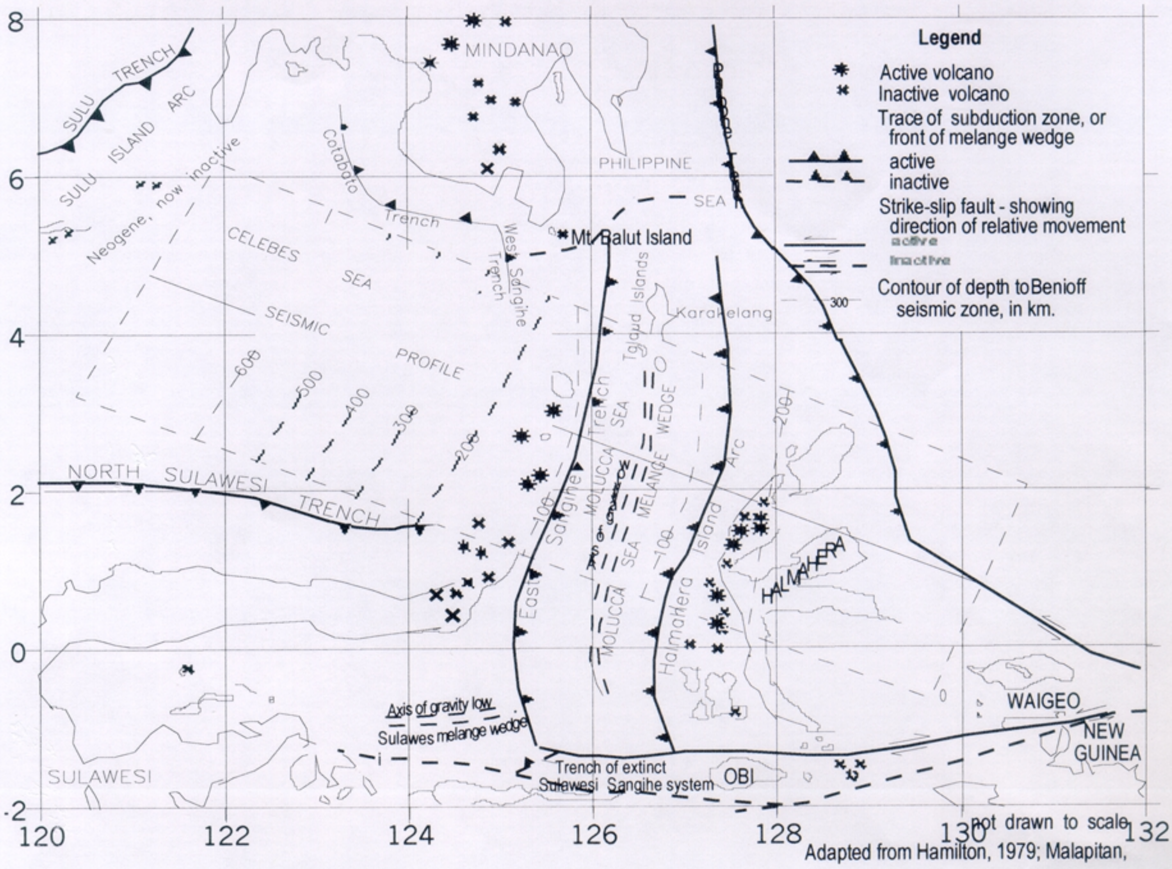

Figure 1. Location of Mt. Balut Island Relative to the Molucca Sea Region

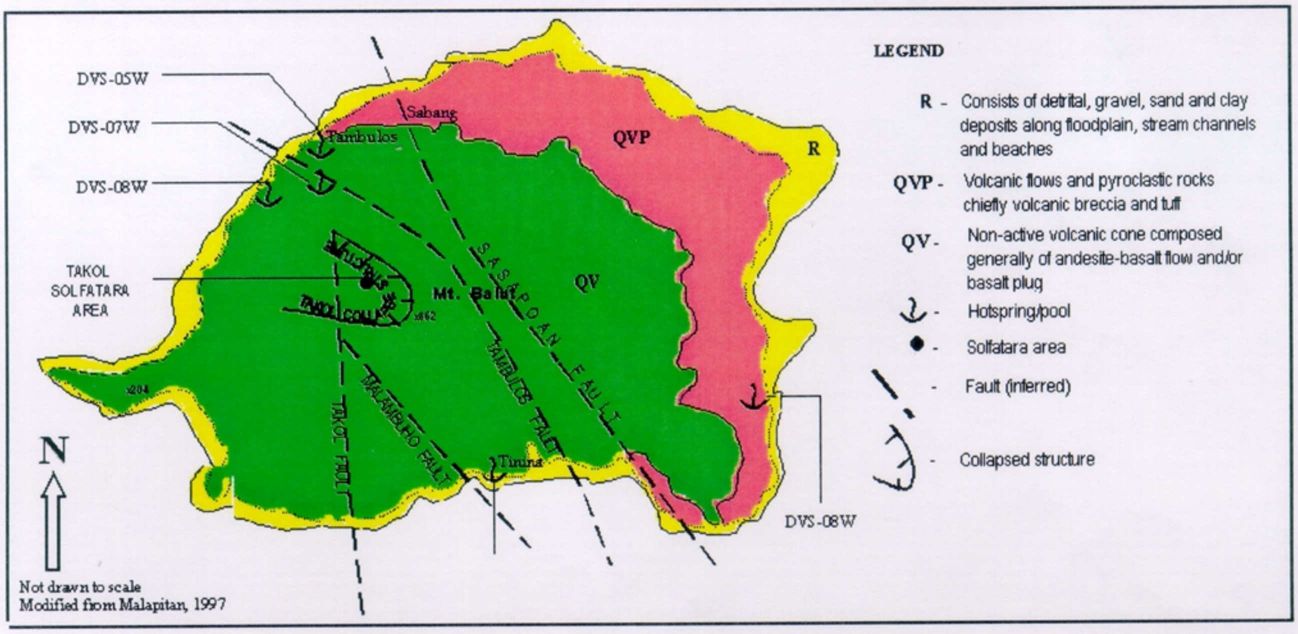

Figure 2. Water sample location and geologic map

Table 1. Results of Chemical Analyses of the Mt. Balut Waters

Sample Code	G97-DVS-05w	G97-DVS-06w	G97-DVS-08w	G97-DVS-09w	G97-DVS-10w
Field Temp., ^{o}C	75	38	74	29	39
PH*	2.73	6.94	2.76	7.27	6.72
Na	164	118	124	10500	159
K	52	11.9	33.6	344	19.2
Ca	69.4	41.0	101	379	111
Mg	23.5	28.6	20.9	1270	54.1
Li	0.20	<0.05	0.17	0.08	<0.05
Rb	0.22	<0.05	0.18	0.06	0.05
Cs	<0.20	ND	<0.20	<0.20	ND
B	14.3	0.28	14.4	4.28	0.37
SiO_2	230	116	224	0.80	134
SO_4	471	26.0	564	2620	66.9
Cl	279	123	224	18600	216
HCO_3	NA	362	NA	122	606
CO_3	NA	ND	NA	ND	ND

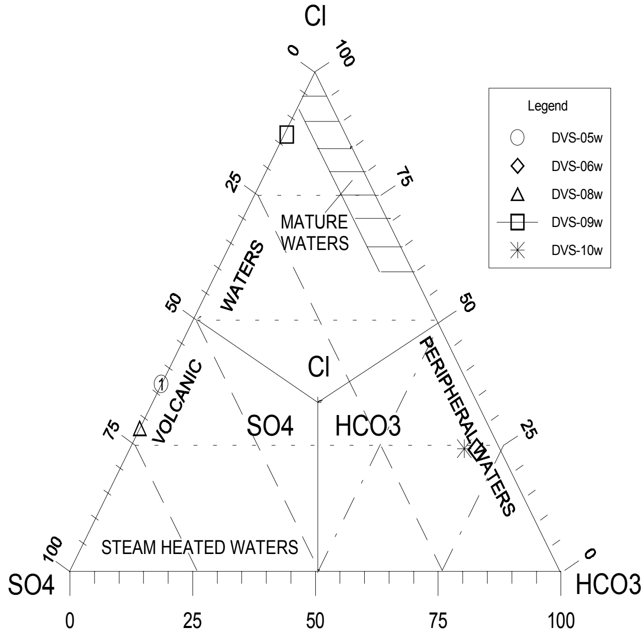

Figure 4. Cl-SO_4-HCO_3 diagram for Mt. Balut waters

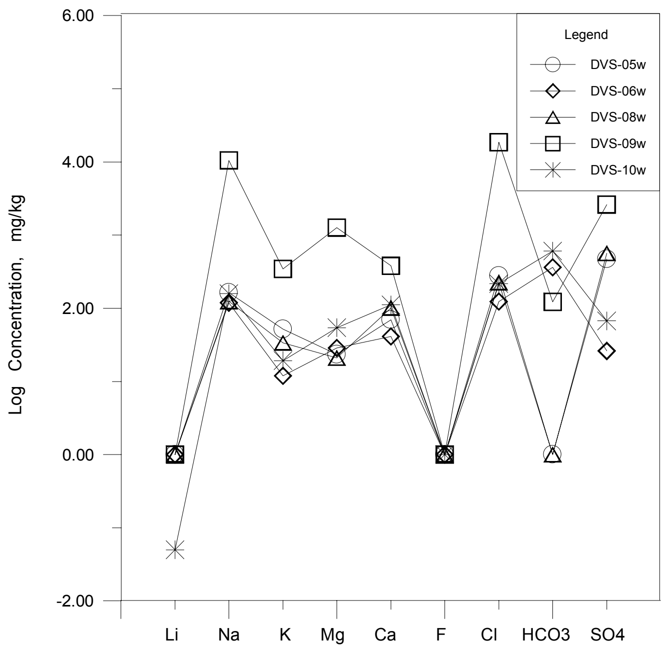

Figure 3. Schoeller diagram shows the predominant ions of the water samples.

Table 2. Silica composition of surface waters in the Philippines

Sample Code	Temp, ^{o}C	SiO_2, ppm
G96-MAG-005w	27	37.8
G96-MAG-006w	27	33.3
G97-SKD-003w	28	30.2
G97-SKD-014	29	26.4
G97-AU-w01	28	30.0
G97-AU-w03	22	32.3
G97-SUL-04	27	38.1
G97-SUL-05	27	30.9
G97-DVOr-02	28	39.1
G97-QUI-03	29	32.4
G97-AU-06	28	31.7

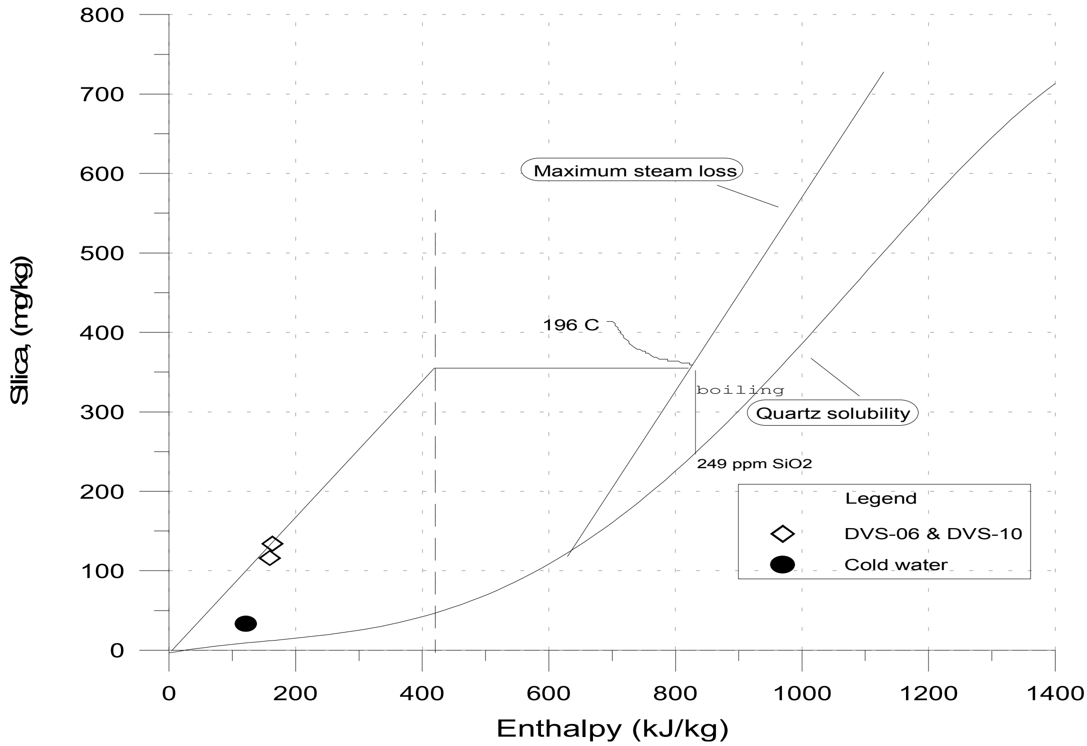

Figure 5. Silica-enthalpy mixing plot for Mt. Balut water