Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Detailed Resource Assessment of Selected Low-Enthalpy Geothermal Areas in the Philippines

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Keywords: Resource Assessment, Low-Enthalpy, Exploration, Philippines

ABSTRACT

Most of the country's high enthalpy geothermal resources have already been developed into commercial operations, making the Philippines second largest power producer of geothermal energy in the world. To further diversify the country's geothermal energy development, the Department of Energy (DOE) is currently implementing a locally-funded project "Detailed Resource Assessment of Selected-Low-Enthalpy Geothermal Areas in the Philippines" from January 2011 up to December 2014.

The main objective of the project is the further the exploration of low-enthalpy geothermal areas that might be applicable for power generation, especially in the remote areas hosting the resource.

Integrated geoscientific surveys have already been completed in the three islands based geothermal prospects. Results of the studies revealed that the Balut Island geothermal prospect is a high enthalpy resource with an estimated reservoir temperature ranging from 175°C to 200°C and potential capacity of around 6-14 MWe, while no exploitable geothermal resource has been delineated at theBanton Island geothermal prospect. The Maricaban Island geothermal prospect on the other hand has been found to possibly host a reservoir at a most likely temperature of 150°C. It is on this premise that the drilling of two thermal gradient wells has been decided on Maricaban Island geothermal prospect to commence in the 3rd quarter of 2014. The success of the project will pave the way for the exploration and development of the other low-enthalpy geothermal resources in the country.

1. INTRODUCTION

The locally-funded project "Detailed Resource Assessment of Selected-Low-Enthalpy Geothermal Areas in the Philippines" is currently being implemented with the aim of characterizing the various low-enthalpy geothermal resources in the Philippines. These low-enthalpy geothermal areas remain untapped and largely ignored by investors because they are lacking the impressive thermal manifestations as compared to the already developed high-enthalpy geothermal areas. With the development of binary power systems using organic Rankine technology, these low-enthalpy geothermal prospects are now suitable for power generation. Aside from this, low-enthalpy geothermal areas may also be used for direct applications, such as, but not limited to industrial, agricultural, tourism and health applications. The development of these resources will be beneficial to the host community as they are typically located in remote areas.

In order to further diversify the country's geothermal resources, DOE is leading the exploration and development of low-enthalpy resources to produce a comprehensive report or database. This database in turn will be made publicly available to ensure private investor participation in the development of geothermal resources through the awarding of Geothermal Service Contracts (GSC).

The activities for the project, as provided by DOE are the following: 1) review of available data, 2) remote sensing and aerial photo interpretation, 3) semi-detailed to detailed geological, geochemical and geophysical (Controlled Source Magneto Telluric) surveys, 4) resource characterization and conceptual modeling and 5) drilling of 1-3 slimholes with an accumulated depth of 1,500 m. The project has selected three (3) geothermal potential areas based on measured spring surface temperature, estimated reservoir temperature and the fact that it should be an isolated area. Summary of the areas is shown in Table 1.

Table 1: Summary of the selected geothermal areas with measured spring surface temperatures and estimated reservoir temperatures based on geothermometers. Taken from National Inventory of Philippine Geothermal Resources; *tbd* – to be determined.

Prospect area	Surface temperature (^{0}C)	Estimated Reservoir temperature (^{0}C)
Banton Island, Romblon	64-68	237
Balut Island, Davao del Sur	66-70	196
Maricaban Island, Batangas	61-80	*Tbd*

The total budget of the project is 60 Million pesos (~US$ 1.3 M @ US$1=PhP45) and it is to be completed within four years. Each geothermal area has been allocated a budget of 10 Million pesos to cover the surface geoscientific studies for the three areas while 30 Million pesos is the budget for the drilling of 1-3slimholes with an accumulated depth of 1,500 m in the most promising geothermal area. To ensure efficient implementation (Table 2), the project has been contracted-out to a qualified service provider to carry out the activities where DOE acts as the approving authority for the result of each activity and at the same time the project acts as a venue for capacity building and transfer/sharing of knowledge between experts.

Table 2: Implementation schedule of the low-enthalpy project. The entire year of 2012 has been used for the preparation of bidding materials for the geoscientific surveys.

Work Program	FY 2012		2011				2012				2013				2014			
	Target	Actual	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q
1. Reconnaissance geological and geochemical survey	three (3) geothermal area	three (3) geothermal area																
2. Data package prepartion for the contract-out service for integrated geoscientific survey	three (3) geothermal area	three (3) geothermal area																
3. Inception Workshop	three (3) geothermal area	three (3) geothermal area																
4. IEC and LGU coordination	three (3) geothermal area	three (3) geothermal area																
5. Socio Economic Profiling	three (3) geothermal area	three (3) geothermal area																
6. Conduct of detailed Geological, Geochemical and geophysical survey	three (3) geothermal area	three (3) geothermal area																
7. Resource modeling. Presentation and evaluation of geoscientific results	three (3) geothermal area	three (3) geothermal area																
8. Data package for slimhole drilling services	one (1) promising geothermal area	one (1) promising geothermal area																
9. Inception workshop	one (1) promising geothermal area																	
10. IEC and LGU coordination	one (1) promising geothermal area																	
11. Drilling of slim-holes	one (1) promising geothermal area																	
12. Well characterization and evaluation	one (1) promising geothermal area																	

LEGEND: Project Implementation for Banton and Balut Island geothermal prospects; Project Implementation for Maricaban Island geothermal prospect; Slimhole drilling projected timeline; ★ Awarding of contract for geoscientific survey/slimhole drilling

IEC-Information and Education campaign;
LGU - Local Government Unit

2. LOCATION AND ACCESSIBILITY

All three selected geothermal prospects are island based, distributed in the north, central and southern Philippines (Figure 1). Balut Island is located in Mindanao, Maricaban Island off the coast of Batangas and Banton Island is found in the Romblon group of Islands.

Balut Island is located about 14 km off the southern coast of Batulaki Peninsula in the southern tip of Mindanao Island across the Sarangani Strait. The island can be reached from Manila by commercial flights to General Santos City in Sarangani Province and thence by direct commercial ferry boat. Sea travel normally takes about 6 hours depending on the cargo load of the boat and sea condition. Other routes are available along the coast of Saranggani Province but the route from General Santos City is the common take-off point to the island. The island has a very poor road network and access to different places is normally by hiking and horseback or motorbike riding along tracks and trails.

Banton Island is equidistant between Marinduque Island to the north and Tablas Island to the South. Accessibility from Manila is a combination of land and sea travel which takes 8 to 12 hours depending on the port of origin in the Luzon mainland, either from the Batangas City port or Dalahican port in Lucena City.

The Maricaban Island is accessible from Manila, via a combination of land and sea travel via South Luzon expressway (SLEX) and Southern Tagalog Access Road (STAR) expressway to Batangas City and Calumpan Peninsula and thence to Maricaban Island across the narrow Maricaban straight. The journey takes a total of 4-5 hours depending on the mode of transport. There are two commercial ports on the Calumpan peninsula, one in Talaga, Mabini along the eastern side and another in Anilao, Mabini on the western coast. There are no roll-on, roll-off (RoRo) commercial ferry boat services to and from the island, the same case as for the other two island prospects.

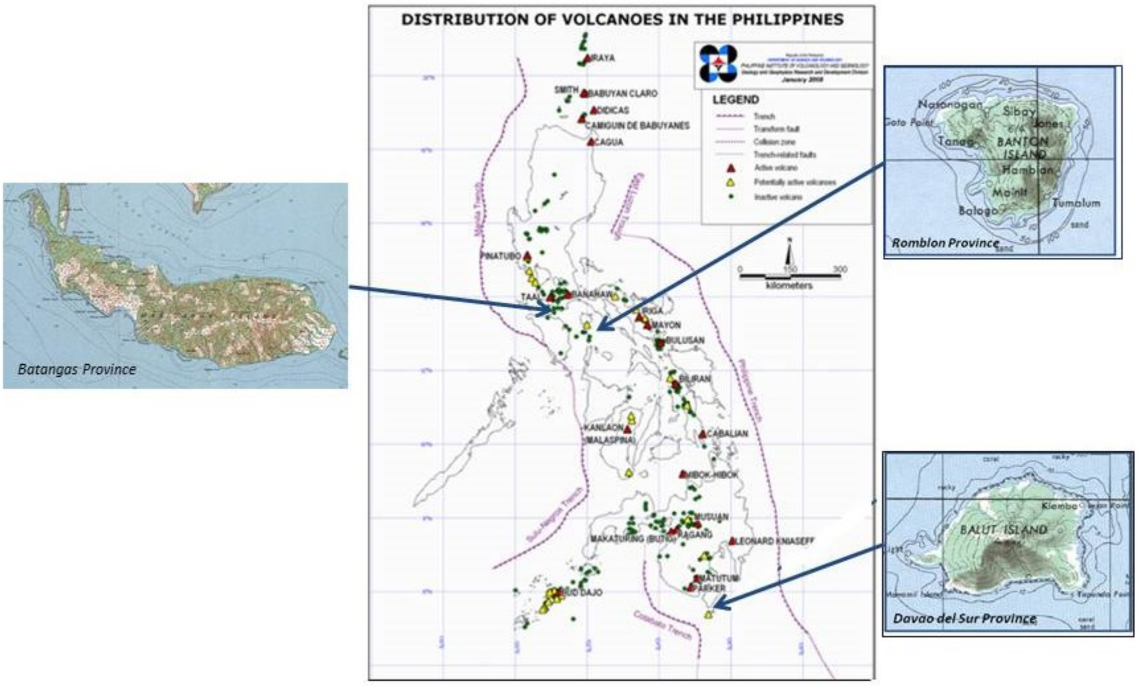

Figure 1: Location of the candidate geothermal prospects shown against the distribution of volcanoes in the Philippines. Modified from Tolentino, et al. (2014).

3. SUMMARY OF EXPLORATION SURVEYS

Discussions on this part of the paper will be written after the findings of FEDS Energy Resources and Development Services, Inc. and references cited therein who was awarded the contract to carry out the geoscientific activities, both pre-survey and survey phase of the project.

3.1 Balut Island Geothermal Prospect

Balut Island is a Pliocene-Quaternary emergent submarine volcano formed from the sustained buildup of basaltic to andesitic lava flows and pyroclastic material from at least five eruption centers, with Mt. Balut as the youngest and highest peak. The most dominant structure is found in the area trends NW-SE, parallel to the Cotabato fault zone, with some N-S and NE-SW trending faults. The location of the thermal manifestations in the area suggests that fluid flow is structurally controlled.

Thermal manifestations in the area consist of solfataras at Gumtago, acidic hot springs at Cayupi and Tambulos, and warm neutral-pH springs (Figure 2). All thermal springs have high Cl and SO_4 content although the previous and present report has not found a representative hot spring of reservoir fluids. Tolentino, et al. (2014a) further investigated to explain the source of high temperature, Cl and acidity of the thermal springs by cross-plotting the SO_4 vs. pH and Cl vs. Mg. In the report, it is confirmed that an increase in temperature shows an increase in SO_4 content and pH. The positive correlation indicates that the springs are actually steam heated. The result of the Cl vs Mg on the other hand shows that the spring waters are a product of mixing and dilution of seawater and groundwater, thus are all shallow in origin. To explain the source of high temperature, the existence of a gas cap underneath that supplies heat and H_2S to the thermal springs is inferred. Reservoir temperature on the other hand is estimated to range from 175-200°C based on gas geothermometry. A separate paper further explains the geochemistry of the Balut thermal springs.

Following the resistivity imaging in Anderson et al. (2000), where resistivity models follows a high-low-high sequence, the 1-D resistivity model taken from the CSMT survey of the prospect follows the same sequence. The low conductive layer represents the clay cap, where the updoming represents the upflow region while thickening of this clay cap is the outflow region. It is further characterized by a high resistivity surface unit present only near Balut peak and Batoganding (>50 ohm m), a moderate resistivity 2nd unit (20-30 ohm-m) which is found from surface at the slopes of the volcano outward, and a conductive 3rd layer (10-30 ohm-m) traced from the volcanic peak and further to the west. The conductive 3rd layer is observed to be thinner at the central part (volcanic edifice), thickening towards the NNW and SSE. The elevation of the bottom of this conductive layer (approx. -1,200 masl) is lowest near the Balut volcano.

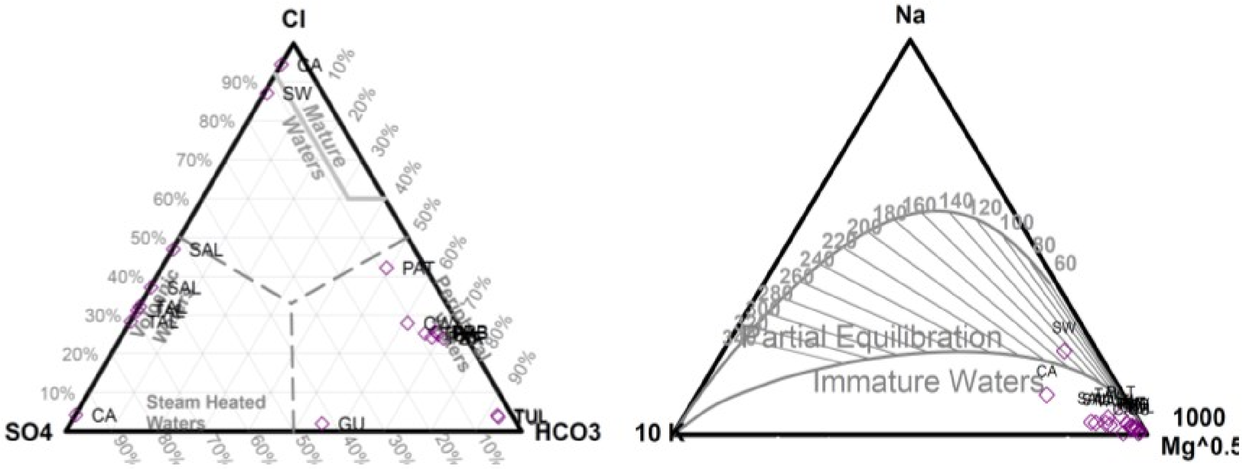

Figure 2: Ternary diagram for the thermal spring of Balut Island geothermal prospect adapted from Baltasar, et al. (2013). In the Cl-HCO_3-SO_4 CA is found to be "mature" and the rest are either steam-heated or peripheral waters. However, as further analyzed by Bayon in Tolentino, et al. (2014), all thermal springs are shallow in origin. In the Na-K-Mg diagram, it shows that all thermal waters are immature and are therefore unsuitable for geothermometer, thus supporting the finding of shallow origin thermal waters. *Legend: Cayupi (CA), Batoganding (BA), Patuwa (PAB), Proper (PRB), Palabuno (GU), Sabang (SAL), Tambulos (TAL), Pandaring (PAT), Tubal (TUL) & Unknown Sitio (TI).*

From the geoscientific studies conducted in the area, it is evident that an active geothermal system exists in the area. The young volcanic peak (Mt. Balut) is the heat source that drives the convection in the area. The upflow, based on CSMT and occurrence of Solfatara is beneath Gumtago and Balut peak (Figure 3). The fluid then out-flows in the NW, SW, SE and E directions through the structures identified in the area. The source of the different thermal manifestations in the area is shallow and driven by the existence of a gas cap in the region. But with seawater incursion in the same area, the thermal activity in the Gumtago Solfatara is also reduced. The size of the possible geothermal resource is estimated to be between 4-9 km^2 (Figure 4).

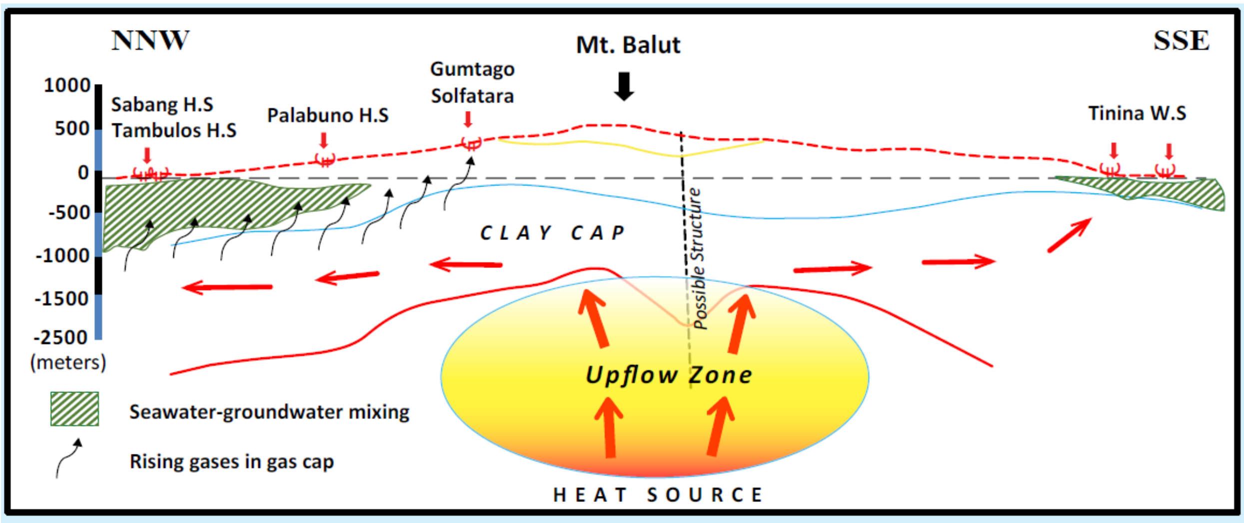

Figure 3: Integrated conceptual model of the Balut geothermal prospect adapted from Tolentino et al (2014). A "gas cap" heats up the hot spring from Sabang to Cayupi, including the Gumtagosolfatara. Sea water incursion on the other hand is inferred to have affected the Gumtago Solfatara, reducing the thermal activity of the area.

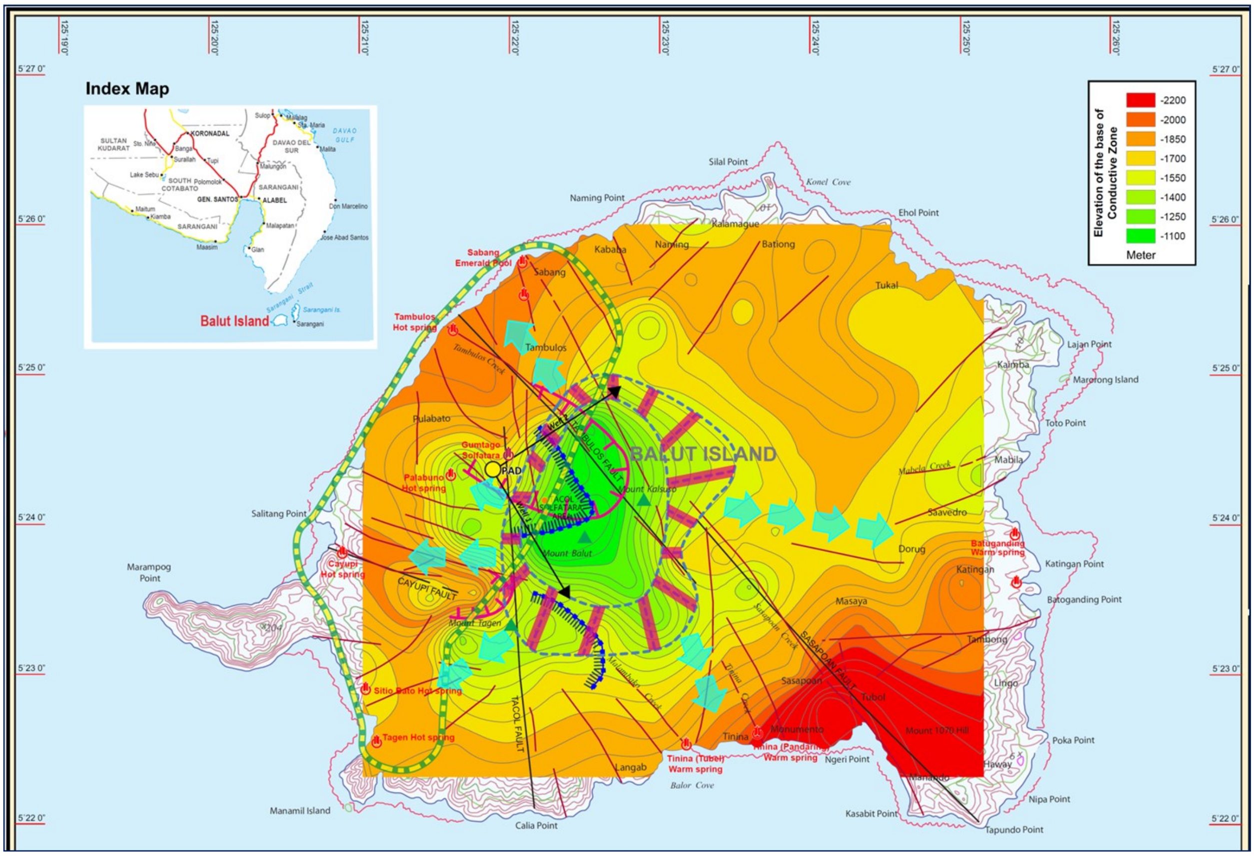

Figure 4: Aerial view of the geothermal resource in Balut Island, showing the minimum and maximum coverage based on CSMT data and out-flow zones (blue arrows). Green boundary line is the estimated coverage of the "gas cap". Adapted from Tolentino et al. (2014).

3.2. Banton Island Geothermal Prospect

Banton Island is at the southernmost portion of the Pleistocene-Quaternary West Luzon volcanic arc which resulted from the subduction of the South China Sea oceanic crust along the east-facing Manila trench. Based on rock petrology, Banton volcano may have been active during the Pliocene period. Four (4) major faults, trending SW-NE were mapped in the area. Within their vicinity, emanate the thermal springs of the area, suggesting that the thermal springs are structurally controlled.

All thermal springs in the Banton Island prospect are sub-tidal, exposed to the atmosphere only during low tide. These thermal springs are located along the western shoreline of the island, bounded by 2 parallel NE-SW trending faults and within the suspected collapse structure. There are no Solfatara and acid springs in the area. Cl levels of the thermal springs are very high (2,000 ppm to 7,000 ppm), even compared to the high enthalpy areas (Cl=1,500 ppm to 3,600 ppm) in the Philippines. Figure 5 shows the ternary plots of the spring waters of Banton Island, showing rather mature, chloride-rich waters that has partially equilibrated with host lithology. Although it may be attributed to its sub-tidal location, further investigation was made by Tolentino et al. (2014a). By analyzing the cross plot between Cl vs. Mg and Cl vs. SO_4 it was found out that the thermal springs are the result of mixing and dilution of seawater and groundwater, thus shallow origin. From this, no temperature estimate was made.

Analysis of the CSMT data shows that the Banton Island geothermal prospect has no resistivity anomaly that is typical in a high terrain geothermal prospect. The resistivity values of the area are high, although they decrease with depth. The low resistivity values are confined and appear not connected with each other. Thus from the result of the CSMT survey, no geothermal resource was delineated (Figure 6).

Although there is clear evidence of volcanic activity in Banton Island, the inferred Pliocene age of such an activity eliminates the possibility of an active heat source underneath the island prospect. FEDs believe a much younger volcanism (Quaternary) is required to develop and sustain an active geothermal convection cell.

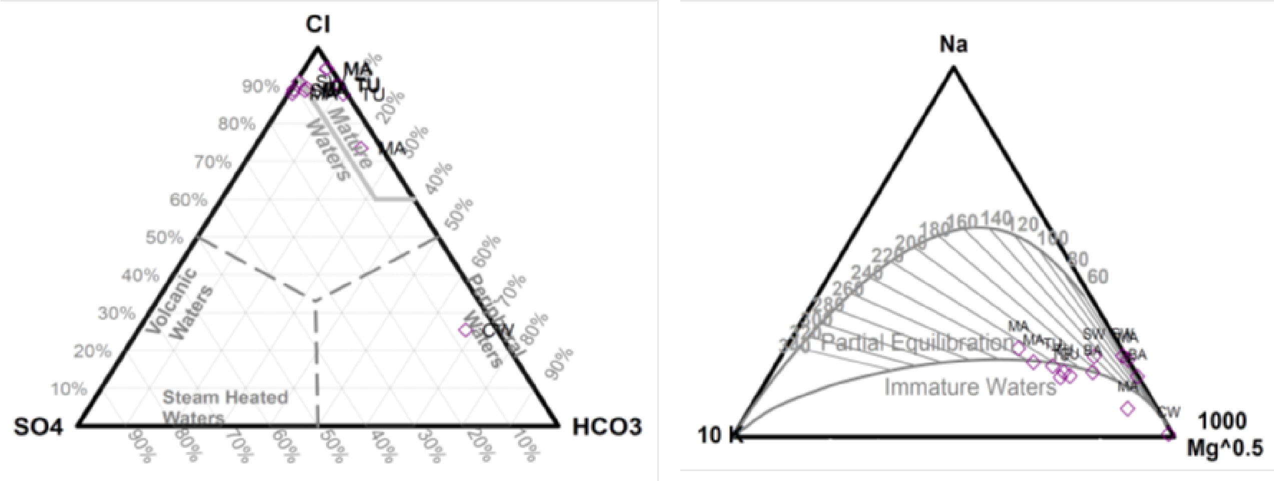

Figure 5: Banton Island geothermal prospect ternary diagram adapted from Baltasar, et al. (2013). Neutral Cl rich waters characterize the major thermal springs of Banton geothermal prospect as seen in the Cl-SO_4-HCO_3 diagram. Likewise, in the Na-K-Mg diagram majority also plots in the partial equilibration region of the diagram which suggests that it cannot be used for geothermometry calculations. As further analyzed by Bayon in Tolentino, et. al. (2014), these waters are all shallow in origin and thus no reservoir temperature can be estimated. Legend: Balogo (BA), Seawater (SW), Mainit (MA), Tungonan (TU) &SitioTubigan (CW).

There is no geochemical evidence to suggest the presence of a deeper, bigger and hotter liquid reservoir. The narrow range of spring temperature, albeit significantly high, also implies that the heat source for the thermal springs is close to the location of the springs, and much higher temperatures at depth are unlikely. This is consistent with a much colder and decadent Pliocene heat source.

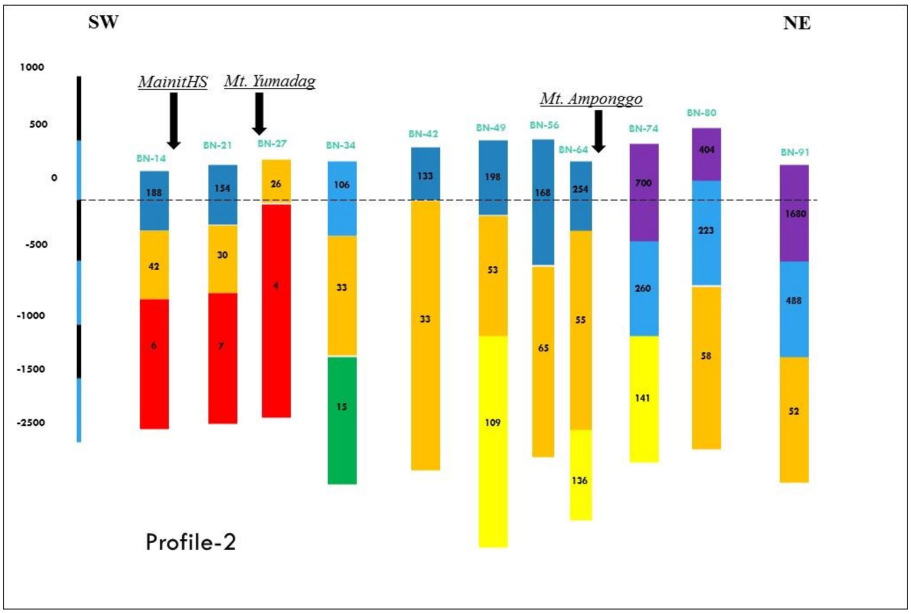

Figure 6: 1-D resistivity model of Banton Island geothermal prospect. It clearly shows the inconsistent distribution of resistivity values. Adapted from Tolentino, et al. (2014).

3.3 Maricaban Island Geothermal Prospect

Maricaban Island lies at the junction of the north-northwest trending Pleistocene-Quaternay volcanic chain making up the West Luzon volcanic arc and the NW-SW trending Macolod Corridor. The arc formation was caused by the subduction of the South China Sea oceanic crust along the east-facing Manila trench. This chain starts with Mt. Pinatubo in the north and proceeds southward through Bataan Province and Batangas Province, thence to Mindoro Island where the chain continues with the volcanic centers Mt. Naujan, Mt. Montelago, Mt. Pola and Mt. Dumali.

Four thermal manifestations are found in the localities of Gamao, Papaya, Talahib and Recudo on the eastern and southern coasts, respectively. No solfataric or fumarolic features, acidic springs and silica sinter deposits were found in the prospect. This observation suggests that the prospect may host a low temperature resource. The spring temperature ranges from 48°C (Gamao) to 81°C (Papaya). There is no smell of H_2S odor in the vicinity but limonite deposits are on the flowpath. All spring samples are near-neutral in pH (Figure 7). Further work by Bayon et al. (2014) investigated the possible fluid source of the thermal springs. From the Cl vs Mg, Cl vs SO_4 and isotope cross plots **(**Figure 8**),** it can be deduced that the thermal spring discharges from a Cl-rich source, although it is clear that this source is also seawater rich. The thermal discharges were termed “reworked” seawater because of the generally lower mineralization that can be attributed to water-rock and fluid-fluid interactions triggered by elevated temperatures as compared to present-day Maricaban seawater. Deep fluid temperature estimates give a range of 100-240°C based on several geothermometers although the overall appearance of the thermal springs and the lack of impressive thermal manifestations would suggest that the "reworked" seawater temperature is closer perhaps to 150°C rather than 200°C.This temperature estimate however should be treated with caution as the thermal springs are considered diluted.

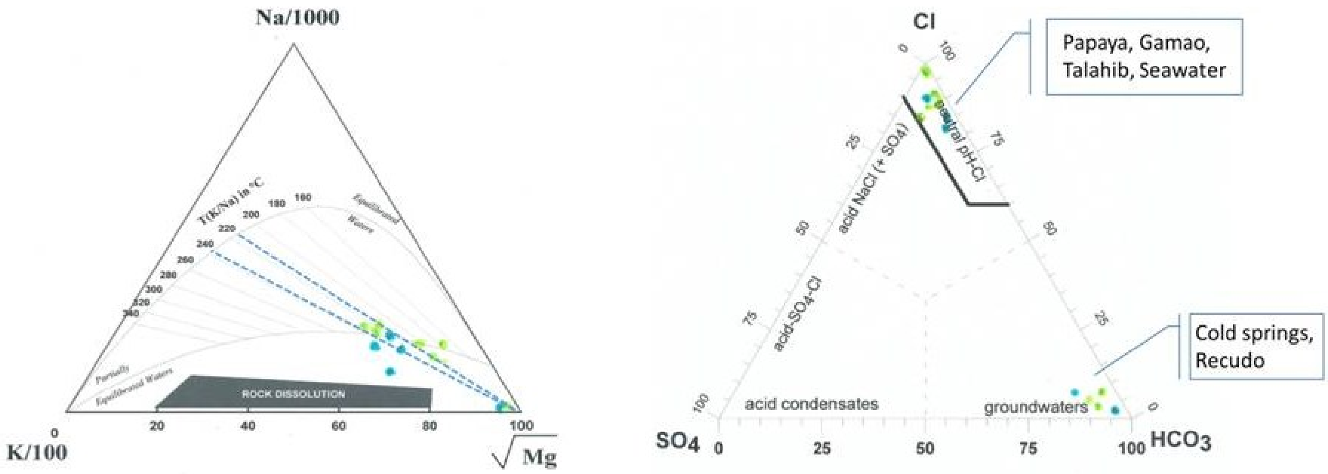

Figure 7: Maricaban Island geothermal prospect ternary diagram adapted from Bayon et al. (2014).Blue dots represent data of the present survey while green dots represent the old survey. In the Cl-HCO_3-SO_4diagram, the thermal springs plots close to the Cl apex because of the high Cl content. The Na-K-Mg diagram on the other hand gives one of the temperature estimate of the likely source temperature.

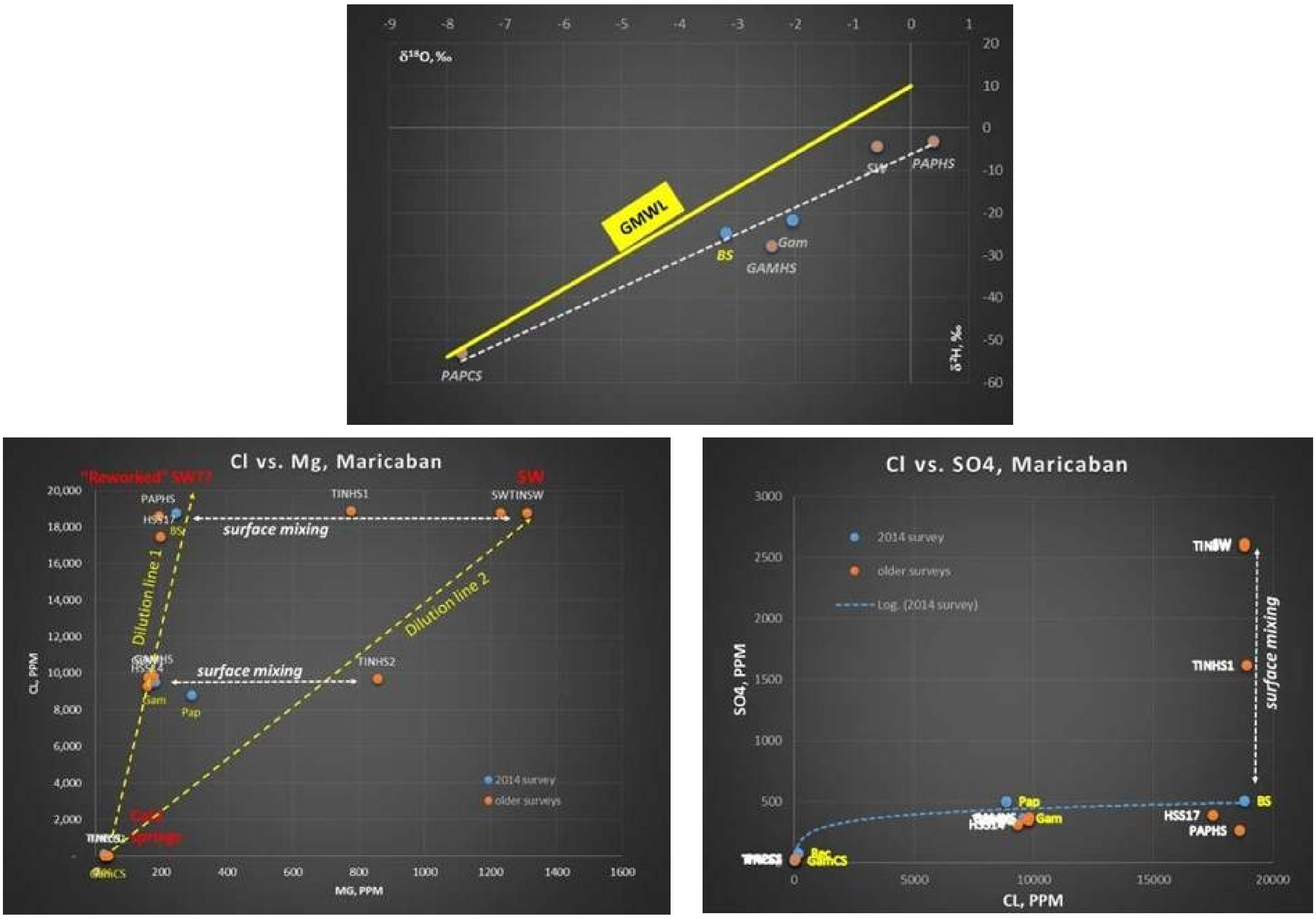

Figure 8: The fluid source was analyzed by Bayon et al. (2014) by using the following cross plots: Isotope cross plot (on top), Cl vs Mg cross plot (lower left) and Cl vs SO_4 cross plot (lower right). It is clearly shown in this figure that the thermal spring discharges from a different source other than seawater.

Geophysical investigation with stations and profile lines shown in Figure 9 using CSMT, revealed a conductive layer dominating the Island prospect. However, it cannot be clearly defined if this layer represents the typical clay cap in a geothermal system or an intrusion of seawater as there are no distinguishable frequency contrasts between the two (Figure 10).

Figure 9: Sounding stations and profiles lines for the CSMT survey in the Maricaban Island geothermal prospect. Adapted from Bayon et al. (2014b).

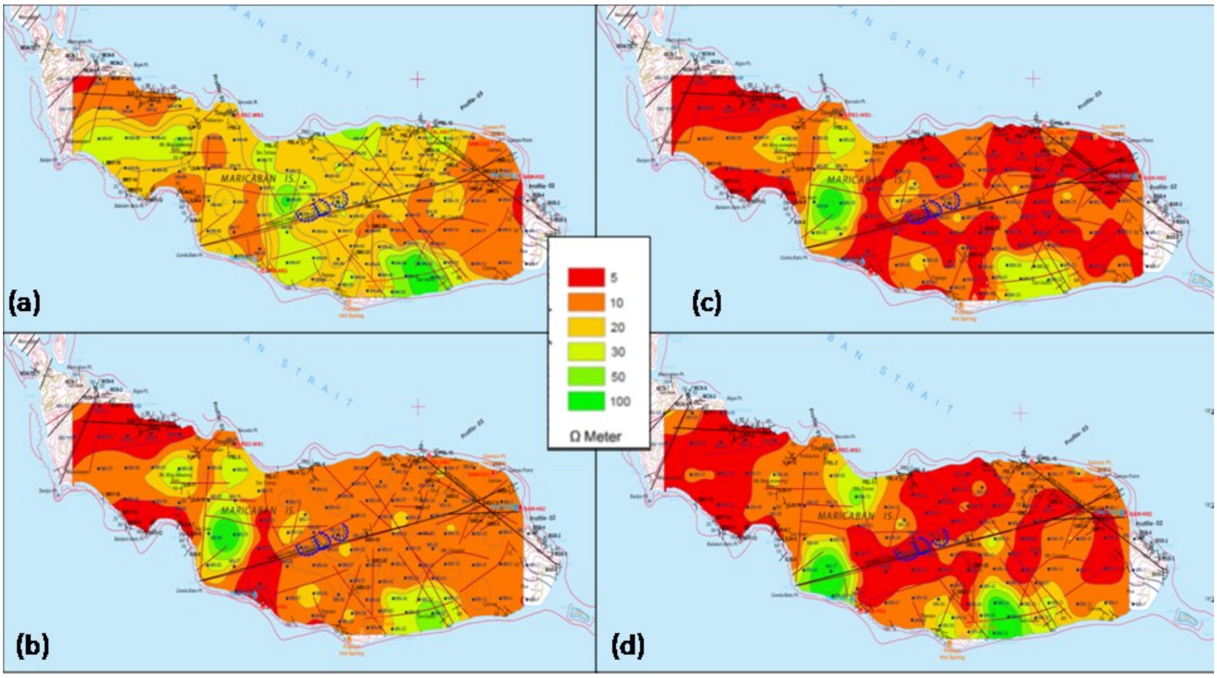

Figure 10: Resistivity contours at different depths at the Maricaban Island geothermal prospect. (a) represents the layer penetrated by freq 5120 hz (shallowest) while (b) and (c) are in the middle depth and (d) is the deepest layer reached by freq 0.625 hz, approx. 1.5-2 km deep. Adapted from Bayon et al. (2014b).

Figure 10 clearly shows the coverage of the low resistivity layer dominated by 10 Ω-m values (orange shaded contour). In Figure 10(a), a region of low resistivity, normally referred to as a conductive layer zone or layer (<10 Ω-m) emerges in the south-central portion of the island. At deeper level represented by Figure 10(b), this low resistivity anomaly develops further and begins to occupy majority of the eastern half of the survey area. It continues to expand at depth and dominates the area to such extent that the area exhibits low resistivity values (Figure 10(c)). It is only at the deepest frequency (Figure 10(d)) where the eastern low resistivity anomaly starts to dissipate, although this low resistivity values of <0.5 Ω-m still occupies a large part of the survey area. From Figure 10, it is clear that the bottom of the conductive layer cannot be seen; therefore the vertical extent of the conductive layer cannot be verified by the survey.

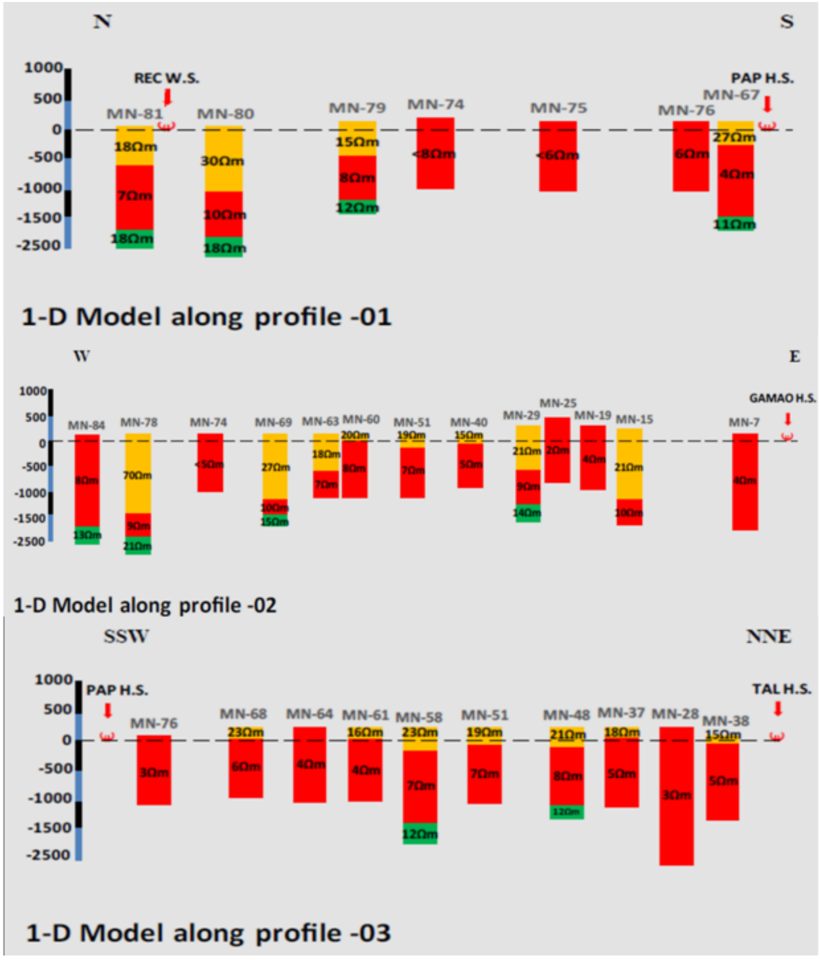

Figure 11: Section of the resistivity profile of the Maricaban Island geothermal prospect. The 1-D model of the three profile lines shows a low conductive dominated layer with a thickness ranging from 1 to 2.5 km.

Figure 11 shows the 1-D model of the profile lines identified in Figure 9. All three profile lines show a distinct low conductive layer dominating the island, with several sporadic lines showing moderate to high resistivity signatures along the top and bottom. With reference to Anderson's resistivity imaging (2000), Figure 11 does not show the typical resistivity profile of a geothermal system in an andesitic area. With this resistivity profile, Bayon et al. (2014b) offered three possible models to explain the source of the thermal springs in the Island. First, the island is likened to the Reykjanes geothermal system in Iceland, where the geothermal system is seawater rich. A deeper reaching MT survey should be used to better image the bottom of the conductive layer of the geothermal prospect. Second, a geothermal system may exist in shallower depths, but since the resistivity signature cannot be detected because of the influence of seawater dominated lithology, the resistivity contrast between the conductive layer and seawater cannot be distinguished clearly. Lastly, there is no geothermal reservoir and the occurrences of the thermal springs are merely localized.

Although all three possibilities may be true, it can only be proven correct if determined by further studies such as with an MT survey and deep exploratory drilling in the future.

4. SUMMARY AND WAY FORWARD

The result of the ongoing "Detailed Resource Assessment of Selected Geothermal Areas in the Philippines" revealed that the project is successful in terms of promoting new underexplored geothermal prospects. The project has proven that the limited thermal manifestations of an area should not be ignored entirely. Initial exploration of such geothermal prospects should always consist of geology, geochemistry and geophysics surveys. Geology has shown the importance of early identification of a possible heat source while geochemistry reveals the chemistry and source of the thermal springs. The geophysics survey on the other hand, using DOE's own CSMT equipment has proven the existence and absence of a likely reservoir in the three (3) geothermal areas.

The integrated geoscientific report for Balut Island geothermal prospect indicates that the area is an intermediate to high enthalpy geothermal area based on the classification cited by Dickson and Fanelli (2004). Thus, future exploration and development in the area should be anchored on the premise that the area is not a low-enthalpy geothermal resource unless proven by exploratory drilling. Therefore, from the integrated resource area of 4-9 km^2, stored heat calculation for the geothermal prospect is around 6-14 MWe. Future works for the area should include detailed studies to determine structural targets for exploratory drilling.

For the Banton Island geothermal prospect, the result of the integrated studies indicates that the area has no favorable conditions to host a geothermal resource. This is backed-up by data on geology, geochemistry and geophysics. Although the area is a known volcanic island, its history is deemed too old to supply the heat needed for a convective reservoir. The origin of the hot springs on the other hand is found out to be shallow and isolated. The geochemistry data is backed-up by geophysics where it shows no resistivity anomaly typical of a geothermal area. From this, no further exploration is recommended for the area.

The Maricaban Island geothermal prospect on the other hand is found to possibly host a seawater geothermal reservoir based on the chemistry of the thermal springs as compared to seawater. However, the existence of the inferred reservoir is still to be confirmed by other geophysical method and studies as the CSMT survey failed to detect the resistivity profile that is typical to andesite hosted geothermal systems. This may be due to three possibilities: a deeper geothermal system exists; the reservoir profile is masked by seawater incursion; there is no geothermal system.

Based on the findings above, the Maricaban Island geothermal prospect was selected to be the venue for the drilling of two (2) gradient wells with an accumulated depth of 1,500 m in the coming 3rd quarter of 2014. The purpose, although it will not prove the existence of the geothermal reservoir due to its shallow penetration, is to collect core and temperature log and fluid samples if necessary. The drilling activity will utilize a small rig most commonly used in the mining industry.

The success of the project in promoting and identifying new geothermal areas has been proven. By using the same methodologies and utilizing the services of third party contractors, similar projects are envisioned to be implemented in the future.

5. ACKNOWLEDGEMENTS

The authors would like to thank their colleagues in the Geothermal Energy Management Division for the useful comments and inputs; the authors would likewise extend their appreciation to the management of Renewable Energy Management Bureau headed by Director Mario C. Marasigan and to the Department of Energyfor the support and for allowing the publication of this paper; and lastly to FEDS Energy Resources Inc. for the sharing of technical expertise during the implementation of the project.

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