Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Controlled Source Magnetotelluric Survey of Mabini Geothermal Prospect, Mabini, Batangas, Philippines

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Keywords: Controlled Source Magnetotelluric, Mabini, Batangas, MBGP

ABSTRACT

Controlled Source Magnetotelluric (CSMT) survey was conducted over the Mabini Geothermal Prospect (MBGP) by Geothermal Division staff in 2000. The purpose of the survey is to characterize the geothermal system underneath the prospect and to test the reliability of the newly repaired CSMT equipment from Japan. CSMT is frequency domain electromagnetic sounding system that utilizes horizontal dipole as an artificial signal source located 4-6 kilometer away from the receiver.

Results of the survey show probable existence of geothermal resource beneath the Hulo Caldera Collapse. Fault structures generally control the resistivity structure of the prospect. This finding is consistent with the earlier study of PNOC-EDC on the existent of hydrothermal resource upwelling in Mt. Binaderahan. However this is still premature and may not be conclusive due to lack of comprehensive geophysical and drilling studies to be used as a basis for correlation. Geophysical studies done in the area were reconnaissance in nature and random stations are a considerable distance apart from each other.

1. INTRODUCTION

In line with Department of Energy's thrust of exploring potential areas for small scale geothermal energy utilization, a reconnaissance Controlled Source Magnetotelluric (CSMT) survey was conducted over the Mabini Geothermal Prospect (MBGP) by Geothermal Division staff from April 10 - May 12, 2000. The purpose of the survey is to characterize the geothermal system underneath the prospect and to test the reliability of the modified CSMT equipment from Japan.

CSMT is frequency domain sounding system that utilizes horizontal dipole as an artificial signal source located 4-6 kilometer away from the receiver. The method is cost effective and ideal for reconnaissance to semi-detailed geothermal prospecting since it covers large areas in less time.

A total of 18 km^2 was covered by the survey wherein fifty-seven stations were occupied utilizing two transmitter dipole sites located in Brgys. Pulong Anahaw and Orense - Anilao East, respectively.

2. DESCRIPTION OF THE STUDY AREA

MBGP encompass the entire Calumpan Peninsula, a chain of NE-SW trending Quaternary volcanic centers situated 15 kilometers SW of Batangas City (Fig. 1). It forms part of the southwestern volcanic belt traceable from Bataan Peninsula, Laguna - Batangas provinces to Mindoro Island. Compared with other geothermal prospects in the country, MBGP is potentially important not only because of its geothermal signatures (such as impressive surface thermal manifestation, relatively high subsurface temperature, etc.) but also for its proximity to the port of Batangas, a potential user of geothermal power. Area surveyed is within the municipality of Mabini. The area is bounded by Bauan on the north, Batangas Bay on the east, Maricaban Island on the south and Balayan Bay on the west. The area is accessible from Batangas City via the well-paved national highway that links the town of Lemery, Bauan and Mabini.

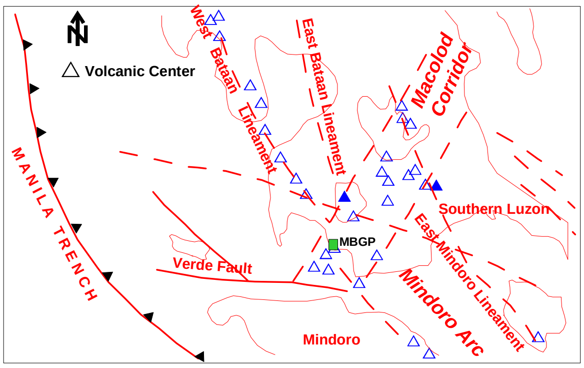

Figure 1: Regional Tectonic Setting of Southern Luzon Showing Survey Area.

2.1 Regional Geologic and Tectonic Setting

The Calumpan Peninsula where MBGP lies is on the southern tip of West Luzon Volcanic arc, a series of Quaternary volcanic chains dotting the Bataan-Zambales Peninsula in the north down to Mindoro Island in the south (Fig. 1). The arc is dissected by NE-SW trending gravity faults and zones of potassium-rich volcanoes collectively known as Macolod Corridor (Defant et. Al., 1989). Macolod Corridor is an inferred volcano-tectono-boundary separating the Bataan Volcanic Segment from the Mindoro Volcano Arc. Calumpan Peninsula sits within the southwest trending series of calk-alkaline volcanic ridges that form part of the Macolod Corridor. These chains of volcanoes are believed to be product of active subduction along the southern segment of the Manila Trench during the Late Tertiary.

2.2 Local Geology and Structures

Eight volcanic rock units consisting mostly of basaltic to andesitic lava flows, volcanic breccias, tuffs and dykes, generally underlie MBGP (PNOC-EDC, 1989) (Fig. 2). These volcanic units were eruptive products of nine volcanic centers dotting the Peninsula from Late Miocene to Late Pleistocene. Occurring within the volcanics, are patches of corralline limestone of Early to Middle Pleistocene age outcropping within the periphery of the peninsula. Its configuration and disposition suggests that this lithology was deposited within the lagoonal environment. The variation of volcanics in the area ranges from basaltic andesite to dacitic, clearly suggest that volcanism in the area has shifted from basic to acid throughout the geologic time. The silicic Manaknit Dome represents the youngest volcanic episode in the area.

Various networks of faults and lineaments of four major trends transect the peninsula: NW-SE, N-S, E-W and NE-SW (PNOC-EDC, 1989) (Fig. 2). Most of these faults are concealed by the Pulang Lupa tuff and occurs either in the form of shear or escarpment and is manifested in the field by the intense shattering of the volcanics and alignment of the thermal springs. In the map and aerial photos these structures are characterized by the alignment of stream and dislocation of prominent mountain ridges in the central portion of the peninsula. The altered grounds in the peninsula are said to be structurally controlled by these faults occurring mostly within fault traces.

The NW-SE set is best represented by Saimsim fault postulated to be the oldest in the area. It originates from the SE slope of Mt. Binanderahan and is traceable to the headwater of Saluyan River down to Sitio Saimsim where it is manifested by intense alteration of the volcanics. It served as fault contact separating the volcanics and the limestone in Nag-iba and dips slightly to the SW. Other faults of the same trend include the Looban Fault, Hulo Fault and the Bagalangit Fault. The N-S and E-W sets are best exemplified by Juana Fault and the Malagaklak fault. These two faults are believed to be responsible for occurrence of wide alteration in Estrella, dislocation of Mts. Gulogod Baboy-Binanderahan ridges and the presence of submerged hotspring along the shoreline of Ligaya. On the otherhand, the NE-SW lineament is represented by Binanderahan Fault, which is seen running along the entire stretch of Panay-Hulo-Binanderahan Sector Collapse. This fault is responsible for the occurrence CO_2 bubbling pool on the upper stretch of Solo River.

2.3 Thermal Manifestation

Thermal occurrences consist of active thermal spring, CO_2 bubbling pools, gas seepage and weak to intensely altered ground (PNOC-EDC, 1989) (Fig. 2). Hot to warm springs were noted occurring in Sitio Mainit, Balanoy, Solo, Ligaya, Sto. Tomas and Pulang Lupa with corresponding discharge temperature ranging from 33^0 - 94^0C. The water has neutral pH, relatively clear and with faint sulfurous odor and characterized by gypsum, aragonite and calcite precipitates in Mainit, Pulang Lupa and Sto. Tomas respectively. CO_2 bubbling pool was noted at the headwater of Solo River emanating from the intensely fractured andesite lava flow while gas seepages were noted in the headwaters of Juana River and at Ligaya and Mainit area. On the other hand widespread patches of weak to intensely altered ground were noted in Brgys. Orense, Ligaya, Estrella, Mainit, San Teodoro and Malimatoc. At depth, these alterations are widespread and concealed by the Pulanglupa Tuff (Reyes and Ruiz, 1978). .

2.4 Previous Works

Being an area of mineral and geothermal interest, MBGP was subject of various exploratory activities since the 50's. Bureau of Mines study on the potential of galena and clay prospects in Mainit and Talaga area. The first reported geothermal exploration activity was conducted by ComVol (now PHIVOLCS) in 1970 consisting of geological mapping, geochemical sampling and geophysical survey. The surveys have established the stratigraphy of the area and outlined three separate upflow zones in Solo, Mainit and Sto. Tomas areas. The surveys were culminated by drilling of 300-m shallow thermal gradient hole in 1981 at Sto. Tomas confirming a geothermal resource with measured temperature of 118^0 C. BED, taking interest from the data generated by PHIVOLCS had included the area in the inventory of different thermal areas of the Philippines. It has assessed the area to be favorable for geothermal development and recommended further reconnaissance works. In 1981, PNOC-EDC conducted similar studies in the area pinpointing a resource with an estimated subsurface temperature of 220^0 C, however they found the resource insufficient for conventional power generation. Reevaluation of the same in 1988 affirmed the earlier finding. From 1988 onward, Office of Energy Affairs (OEA) now Department of Energy conducted a series of reconnaissance to semi-detailed geological mapping and spot geochemical sampling. These studies confirmed earlier findings on the presence of geothermal system beneath the Calumpan Peninsula with Mt. Panay as the postulated heat source. In 1993, DOE conducted environmental baseline study under the RP-Italy Technical Assistance in Geothermal Energy Exploration and Production. The latest study done so far in the area was the 1996 Isotope Studies conducted by the combined team from DOE and PNOC-EDC.

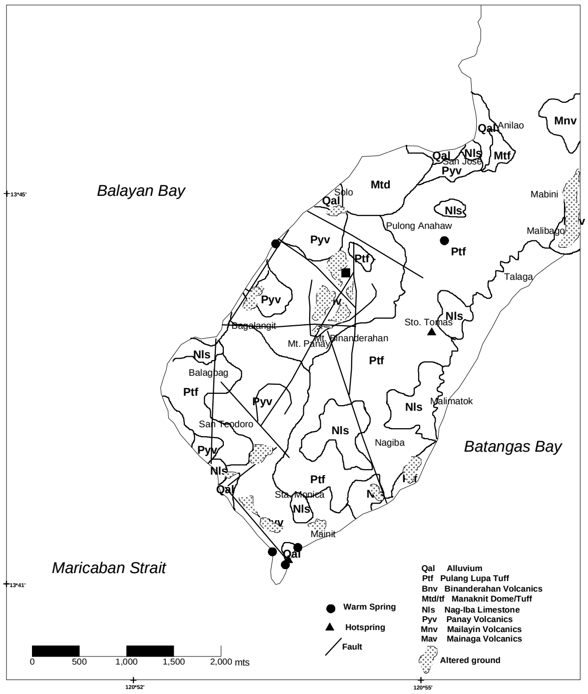

Figure 2: Geology, Structural and Thermal Manifestation Map of MBGP.

3. CSMT BASIC PRINCIPLES & METHODOLOGIES

3.1 Basic Theory

Controlled source magnetotelluric (CSMT) is a frequency domain electromagnetic sounding technique used to establish the three dimensional (3D) apparent resistivity structure of the earth. The method uses a fixed grounded transmitter dipole as the energy source. Orthogonal electric and magnetic field components are measured ideally in the plane wave portion of the field far from the source.

The telluric pots detect the electric fields while the magnetic coil senses the magnetic field. Apparent resistivity is obtained by taking the ratio of the perpendicular, horizontal electric and magnetic field magnitudes. The difference of phase angles between the electric and magnetic field provide impedance phase. Usually the measurements are made in the frequency range of 1 Hz to 1 kHz but in this survey, 0.625 Hz to 5.12 kHz was used.

Below are some basic equations of CSMT:

Apparent resistivity, ρa

$$\rho = \frac{1}{5f} / \frac{E}{H} /^2 \text{ (ohm-m)}$$

Phase difference, φ

$$\Phi = \varphi B - \varphi H \quad \text{(mill-radians)}$$

Equivalent depth of investigation, D

$$D = 356 \sqrt{\frac{\rho}{f}} \quad \textit{(D in meters)}$$

where E is the electric field in mV/m, H is the magnetic field in nT (nanotesla) and f is the frequency in Hz.

3.2 Survey Methodology

A total of 57 CSMT stations were occupied (Fig. 3) within the entire Calumpan Peninsula covering an area of approximately 18 square kilometers. Stations were randomly distributed to an average areal distance of 1 kilometer. Acquisition of resistivity data is through a receiver capable of receiving, collecting and processing telluric and magnetic signals at 14 different frequencies ranging from 5,120 Hz to 0.625 Hz. Measurements were carried out in random style utilizing a "fixed" transmitter site and a roving receiver site spaced 3-7 km apart. The transmitter which is approximately 1.5 km. and oriented N85^{o}E was placed in Brgys. Pulong Anahaw and Orense - Anilao East, respectively. Locations of the proposed station in the field were verified using 1:50,000 M scales map, GPS and thommen altimeter. Since transmitting and receiving was done on the same frequency and simultaneously at a given time, the clock at the transmitter and receiver sites were synchronized first before going out to the field.

4. DATA PROCESSING AND ANALYSIS

The time series data, written in text format are then downloaded and processed respectively using the window based Rx006 Host and CSMT 1-D inversion software (Fig. 4). Initial processing of the data start with the data sorting wherein the processor had the option to reject the bad or extreme data from among those collected. Ten percent of the data extreme was rejected based on resistivity and phase. Smoothing of the curve follow wherein the averaged of data of both the resistivity and phase were interpolated by the program using spline function. Far Field Analysis is then performed either by data analysis through resistivity and phase or by phase only. In the process, two option were given to the user to have 1-D plot: the No Input Layer Structure wherein the program automatically assigned the number of layer models/frequency and the Yes Input Layer Structure wherein the user had the hand on the number of layer models. Both options require station elevation and maximum penetration depth in order to calculate the true resistivity, depth and thickness of each layer. Far field 1D inversion of the data used both the resistivity and phase choosing the no input layer structure option. The final product is a CRT (resistivity-phase-frequency) plot depicting curve trend and distribution of data sets per frequencies. Incorporated in the plots are the average fields and calculated resistivities obtained during the measurement as well as the depth, thickness and true resistivities per layer.

Figure 3: CSMT Stations with Profiles Lines.

The decision to reject or retest station was based on the results of initial processing. Station with wider range of data set per frequency and no apparent curve trend is subject for retesting.

The CSMT data were still subjected to further processing to produce a more refine and acceptable data to be used in interpretation. At this stage, the CRT plots of the individual station according to map location were examined for possible error, noise and surficial effects. To diagnose the occurrences of near field effect and to visualize clearly similarities in trend at depth of the inverted data, correlation among different variables such as apparent resistivity, frequency and depth were made using MSExcel and Grapher programs. After inversion, the data were processed further utilizing Hmap and Dan98.Exe and was finally linked to Surfer to produced isoresistivity maps and cross sections.

Noise analysis, show that majority of the stations have good readings in all of the frequency except some stations in the lowermost and shallow frequencies. Each station were analyze based on the compactness, oneness or closeness of the data population in a particular frequency.

In terms of data quality, less noisy and good data were more accurate and have better fit after inversion than the noisy one.

Examination of the CRT plots show that majority of the stations measured within the Mt. Panay Complex show an increasing resistivity layering at depth which might be due to the presence of dense intrusives beneath the complex while stations within the Mt. Binanderahan-Hulo complex show abrupt resistivity trend indicating presence of geologic structures such as faults or caldera structures. Elsewhere in the survey areas, stations reflect gradual increase in resistivity trend suggesting that the volcanic rocks in these areas were neither severely fractured nor altered.

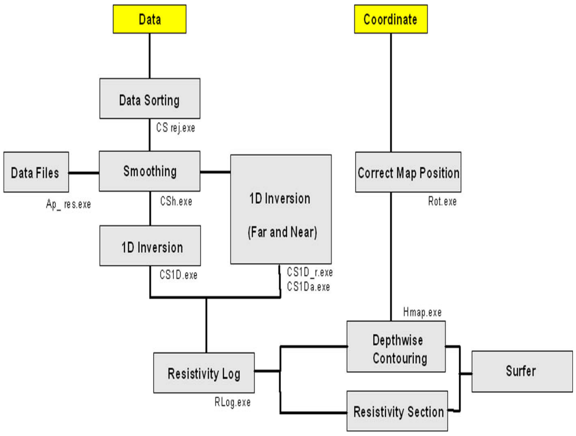

Figure 4: CSMT Data Processing Flow Chart.

5. DISCUSSION OF THE RESULTS

5.1 Isoresistivity Plan Map

5.1.1. At Mean Sea Level

At mean sea level, two broad resistivity low (<40 ohm-m) one in Pulang Anahaw and the other in Mt. Panay-Sta. Monica area were noted separated on the north and bounded on the east (Malimatoc) and southwest (San Teodoro) by blocks of intermediate to high resistive values (Fig. 5). Situated in between the Mt. Panay-Sta. Monica broad resistivity low were two north trending extremely low resistive bodies (<10 ohm-m): one near Malimatoc and the other in Sta. Monica area. The extremely low resistivity body in Sta. Monica was open ended towards the Mainit area. Based on the coincident of the mapped altered ground with the broad resistivity low identified above, we presumed that the said broad conductive bodies represents the top portion of the widespread altered ground believes to be concealed by Pulanglupa tuff.

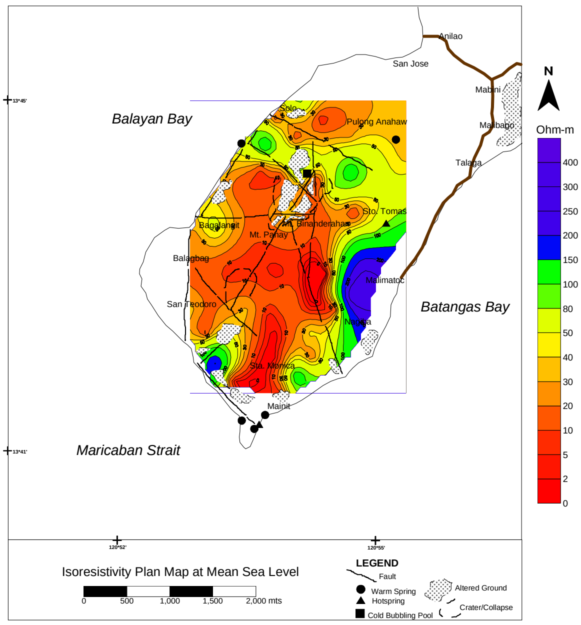

Figure 5: Isoresistivity Plan Map at Mean Sea Level

5.1.2. At -250 meter

At -250 meter below the surface, the widespread altered ground noted above become bigger and is now open-ended in all direction (Fig. 6). The extremely low resistive blocks identified in the middle now break down into smaller segments and are noted in Ilat, Saimsim and Sto. Tomas area. On the other hand, the high resistive values previously bordering the broad low resistivity zones in the east (Malimatoc) and southwest (San Teodoro) noted at mean sea level disappear on this horizon are now replaced by intermediate resistivity values.

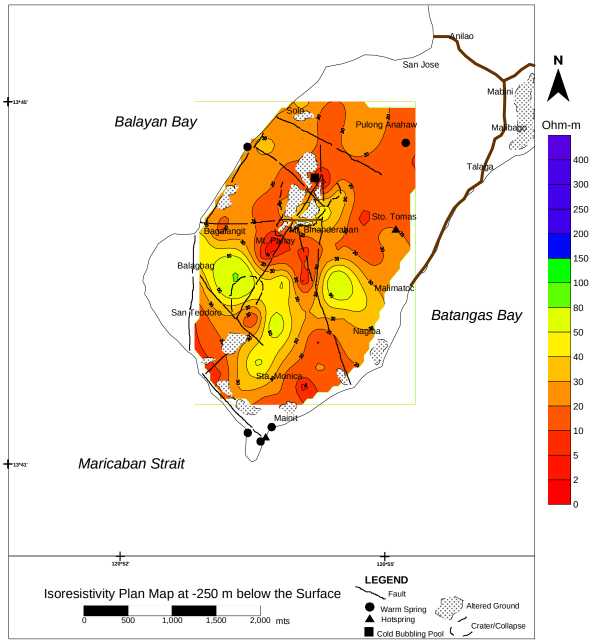

Figure 6: Isoresistivity Plan Map at -250 Meter Below the Surface.

5.1.3. At -500 meter

At this depth, the extremely low resistive blocks identified in the middle now break down into smaller segments (Fig. 7). It is still open-ended toward the north and in the Mainit area and is separated by intermediate resistivity values that goes high toward Mt. Panay-Bagalangit and Malimatoc-Laurel area. The less than 10 ohmmeter anomaly located in the middle increases in size while that of Sto. Tomas remains the same. On the other hand, two less than 10 ohmmeter anomalies, one extending from Sta. Monica to Mainit area and the other in the Solo-Pulong Anahaw area sprung on this horizon. We perceived that this low resistivity zone represent the edge of the altered volcanic rocks encountered by the shallow gradient hole of COMVOL in Sto. Tomas.

5.1.4. At -750 meter

The less than 10 ohm-meter anomalies in the middle and that of Sta. Monica to Mainit increased slightly while the Solo-Pulong Anahaw anomaly slightly decreased (Fig. 8). On the otherhand, the intermediate to high resistive blocks bounding these anomalies increased tremendously and now encompasses Malimatoc and Nagiba in the east and Bagalangit, Balagbag and San Teodoro in the west. For further discussion, the above mentioned anomalies were categorized as follow: Mainit- Saimsim anomaly for the smaller anomaly in south, the Binanderahan-Estrella-Pulanglupa-Sto. Tomas anomaly for the U shaped anomaly located in the middle portion of the survey area and the Pulong Anahaw anomaly for the conductive body located in the north. The Mainit-Saimsim anomaly are open-ended in the south and seem to be bounded by Saimsim Fault in the east while the middle U shaped and Pulong Anahaw anomalies are open ended in the north and are bounded on both sides by the intermediate to high resistive blocks of Estrella, Bagalangit, Nagiba and Malimatoc. We presume that these two major anomalies probably represent the topmost portion of the reservoir of the prospect.

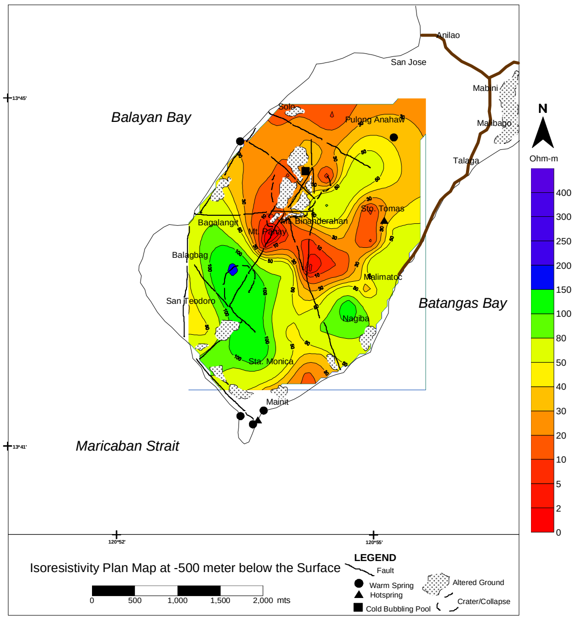

Figure 7: Isoresistivity Plan Map at -500 Meters below the Surface.

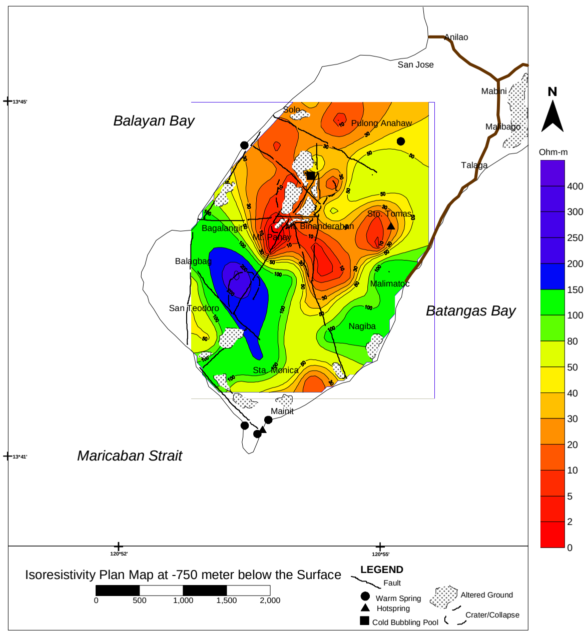

Figure 8: Isoresistivity Plan Map at -750 Meters below the Surface.

5.1.5. At -1,000 meter

No significant change occurred in this horizon except for the slight increased of the above mentioned anomalies and the looming of the Sulo conductive body which is the obvious extension of the middle U shaped anomaly (Fig. 9).125

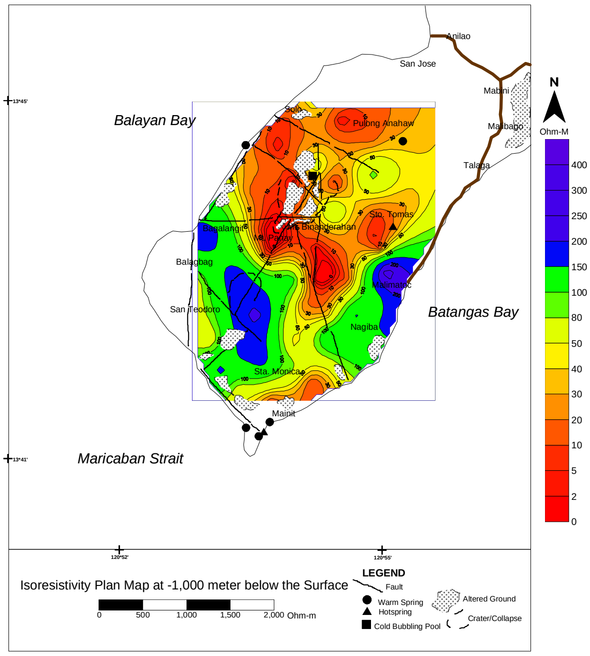

Figure 9: Isoresistivity Plan Map at -1,000 Meters below the Surface.

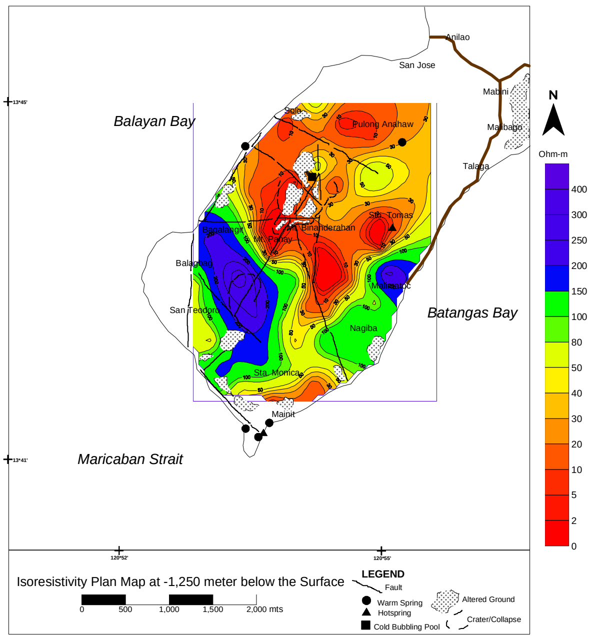

Figure 10: Isoresistivity Plan Map at -1,250 Meters below the Surface.

5.1.7. At 1,500 meter

The middle U shaped, Sulo, Pulong Anahaw and the Mainit-Saimsim conductive bodies slightly increases on this horizon (Fig. 11).

5.1.8. At 1,750 meter

At -1,750 m, the large middle U shaped anomaly taper significantly (Fig. 12). It's less than 10 ohmmeter Saimsim Segment joined with the Sto. Tomas segment while the Binanderahan segment disappears. The southern configuration of the Sulo and Pulang Anahaw anomalies seem to follow the trend of Looban Fault. The Mainit anomaly on the other hand grows considerably in size. The considerable decrease of the middle U shaped anomaly indicates the narrowing of the geothermal reservoir of the prospect.

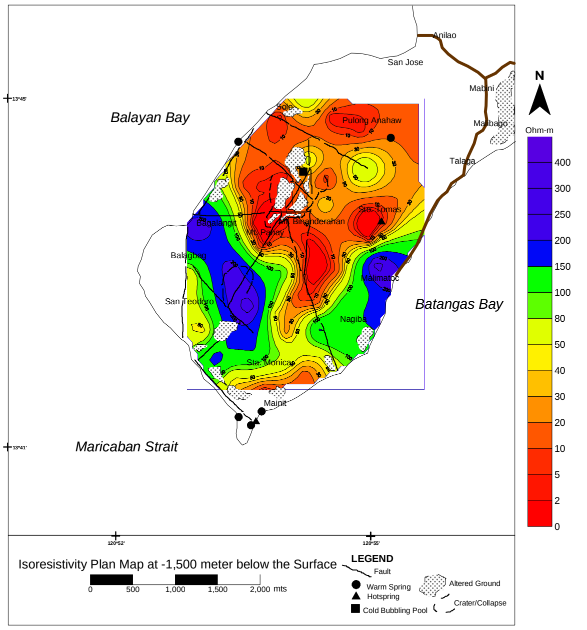

Figure 11: Isoresistivity Plan Map at -1,500 Meters below the Surface.

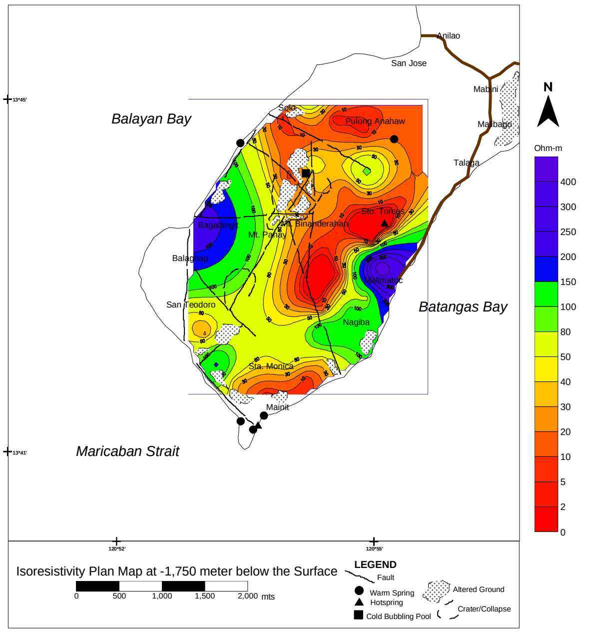

Figure 12: Isoresistivity Plan Map at -1,750 Meters below the Surface.

5.2 Isoresistivity Profile

Several profile line were made to view and characterize the subsurface configuration of the geothermal prospect (Fig. 3). Line A-A' was made across the Mt. Panay-Binanderahan-Hulo Sector. Line B-B' traversed the Mt. Panay Complex, on SW edge of the survey area while Line C-C' cut across the Hulo Sector Collapse. On the other hand, Line D-D' runs longitudinally on the SE edge of the survey area and Line E-E' transect the Mainit-Panay-Hulo area. Remarkable signature of all these profiles was the strong lateral resistivity contrast between stations manifesting presence of 2 or 3D structures at depth. This suggests that faults greatly influence the resistivity make-up of MBGP.

5.2.1. Line A-A'

This line runs from Station Mab8 to Mab49 (Fig. 13). A middle conductive layer, strong resistivity contrast and all low resistivity values signifying either fractured or altered zones characterized this line. The middle conductive layer and the low resistivity zone was in turn capped and underlained respectively by high resistive bodies noted at stations Mab 8, Mab 7a, Mab 37 and Mab 49. Interpreted geological section of this line depicts a basement consisting of down thrown and uplifted blocks separated at depth by Saimsim and Juana Faults. These blocks might either be the Panay intrusives or high resistive Panay (PYV)/Binanderahan Volcanics (BNV). The fractured zone probably consists of argillized or highly fractured PYV while the middle conductive zone was perceived to be consisting either of highly to severely altered PVY or BNV as seen from the outcrop in Balagbag and Pulanglupa area. The severely altered zone is in turn overlained by slightly weathered PYV or BNV. Binanderahan Fault served as a major conduit channeling the geothermal fluid emanating from Hulo Sector Collapse.

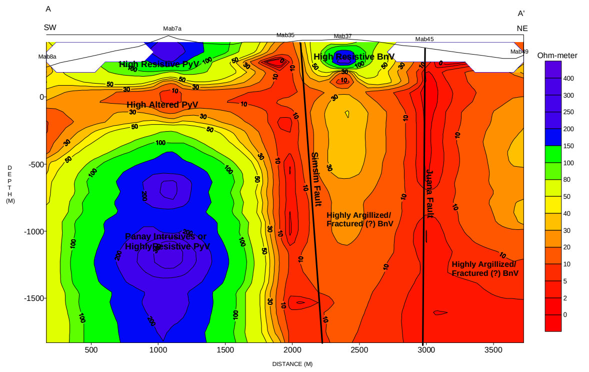

Figure 13: Isoresistivity Profile and Geoelectrical Interpretation along Line A-A'.

5.2.2. Line B-B'

This line runs from Station Mab20 to Mab 14 across the Mt. Panay Complex (Fig. 14). Low resistivity anomaly was noted originating beside the intrusive-like structure occurring beneath the Panay Caldera Complex. The anomaly projects upward and merges with the middle and upper conductive layer at stations Mab20, Mab7a, Mab11, Mab13a and Mab14. Capping the structure at the surface is the high resistive body noted at stations Mab 7a, Mab9, Mab11 and Mab14. Interpreted geological section of the line depict a high level intrusive separated from high resistive PyV by Binanderahan Fault. Capping both the volcanics and the intrusives on the shallower level was the highly altered PYV, which outcrop in Ligaya and Saimsim area. The low is in turn overlained by high resistive PYV and NagIba limestone.

5.2.3. Line C-C'

This resistivity profile runs from Station Mab56 to Mab31 across the Hulo Sector Collapse (Fig. 15). Low resistivity anomalies were noted beneath Mab 45 and Mab 43. At Mab 45 strip of elongated low resistivity anomaly begun at the surface and terminates midway between -1500 m and -1750 m. These anomalies are separated at depth by blocks of intermediate resistive bodies occurring beneath Mab 50, 46 and 31. At shallow depth they merge with the middle conductive horizon of Mab 31 in the SE and to Mab 50 and Mab 56 in the NW. This middle conductive layer is partially overlained by blocks of resistivity high noted at stations Mab 56, Mab 50 and Mab 31. Resistivity contrast in between stations Mab 50, Mab 45, Mab 46 and Mab 43 depict presence of faulted structures such as Juana, Binanderahan and unmapped fault structures beneath Mab 43. Interpreted geological cross section of the line reveals basement similar to LineA-A separated at depth by Juana and unknown fault (?) occurring within the vicinity of Mab 43. The basement is perceived to consist either of Panay intrusives or highly resistive BNV. The fractured zones in between these intrusives bodies are believed to consist of highly argillized BNV and probably represent the hydrothermal fluid channeled along the two faults. Partially capping these lows is the highly altered BNV extending towards Ligaya and Sto. Tomas area.

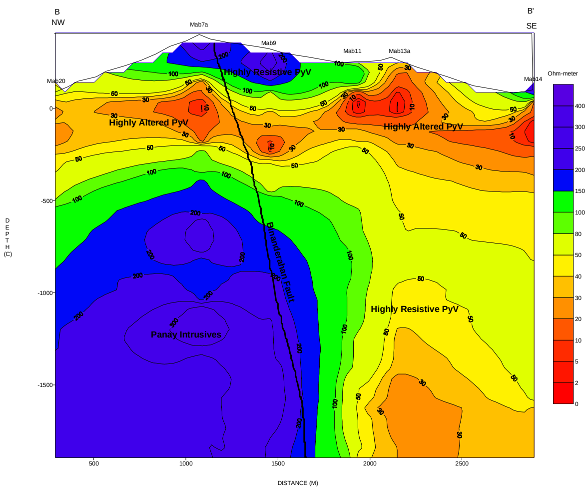

Figure 14: Isoresistivity Profile and Geoelectrical Interpretation along Line B-B'.

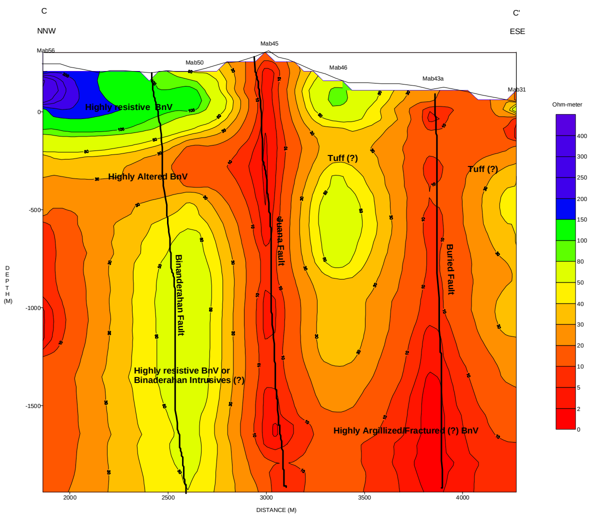

Figure 15: Isoresistivity Profile and Geoelectrical Interpretation along Line C-C'.

5.2.4. Line D-D'

This section transects the NW segment of Saimsim Fault. Two wide and distinct anomalies separated at depth by isolated intermediate resistive structure beneath Mab 34 were noted upwelling beneath Mab 22 and 43 (Fig. 16). At shallow depth (around 200 to 500 M), these anomalies merge with the middle conductive layer that projects laterally in the SW and NE. Strong resistivity contrast noted between Mab 22 and Mab 27 and Mab34 and Mab 43a possibly indicates presence of channeled fluid along Saimsim Fault and unmapped fault beneath Mab 43a. Interpreted geological cross section of the line show a series of faulted basement separated at depth by Saimsim and unknown fault (?) at Mab 43. The basement may consist either of Panay Intrusives or high resistive PyV. The highly argillized zone located in between these intrusive body probably represents channeled hydrothermal fluid along Saimsim and unknown (?) fault. The middle layer is thought to consist of highly to severely altered PYV that outcrops in Balanoy and Sto. Tomas area. It is in turn overlained in some parts by slightly altered PVY or the Pulanglupa Tuff.

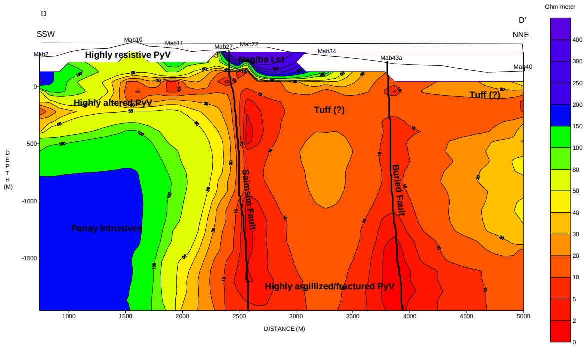

Figure 16: Isoresistivity Profile and Geoelectrical Interpretation along Line D-D'.

5.2.5. Line E-E'

This profile runs from station Mab3 to Mab 47, crossing the offsetted ridges of Mt. Panay and Gulogud-Baboy. An extremely wide anomaly bounded by high resistivity beneath Mab 9 and Mab 52 was noted at the middle portion of the line (Fig. 17). This anomaly merges with the conductive layer of Mab 3, Mab 10, Mab 9 and Mab 26 in the SW and Mab 62 and 47a in the NE. This suggests possible flow of the fluid along geological structures. The undershooting and converging of the resistivity contour at Mab 26 probably depict the edge of Panay intrusives while resistivity contrast between stations Mab 52 and Mab 47a depict presence of Looban Fault. Interpreted geological cross section of the line show a series of differentially uplifted fault blocks separated at depth by Saimsim, Hulo and Looban Faults. The extremely wide anomaly is viewed here as a down thrown block occurring along the NE edge of Panay intrusives. It probably consists of high to severely altered BNV. The up thrown blocks were perceived to consist either of Panay instrusives or high resistive volcanics while the fractured zone is thought to consists of highly argillized BNV. The argillized zone probably represents hydrothermal fluids that are chanelled along Saimsim and Hulo Faults. Capping this zone in the shallow depth is the high to severely altered BNV, which outcrop in Balanoy area.

5.3. Conceptual Hydrothermal Model

The interpreted resistivity structures of the CSMT survey done in MBGP suggest possible existence of geothermal resource beneath the Binanderahan-Hulo Sector Collapse (Fig. 18). This is consistent with the finding of PNOC-EDC on the existence of hydrothermal resource beneath Mt. Binanderahan. The upwelling zone is centered on the collapse and was channeled along the major faults traversing the area.

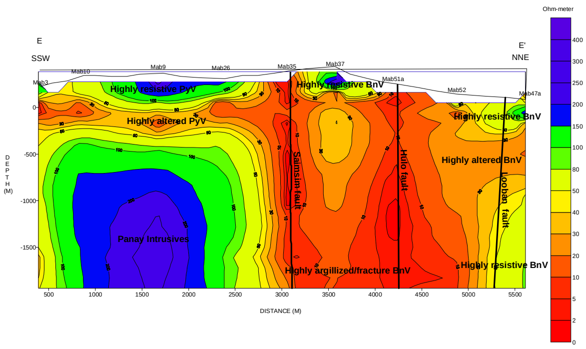

Figure 17: Isoresistivity Profile and Geoelectrical Interpretation along Line E-E'.

There are three prominent outflow directions that can be inferred, based on the position and trend of the different anomaly zones in relation to thermal manifestation and major structures: One is northwesterly to westerly outflow zone towards Hulo and Ligaya area; second is the northeasterly to easterly outflow zone towards Pulanglupa and Sto. Tomas area and lastly southerly outflow towards Malimatoc, Saimsim and Mainit area. The northwesterly to westerly outflow is perceived channeled along Hulo and Magalaklak Faults while the northeasterly to easterly outflow mainly long Saimsim and Juana Faults. On the other hand, an unknown NE and east trending faults are suspected as conduit for the thermal spring in Pulanglupa and Sto. Tomas area. The possibility on the occurrence of these conduits is very evident with the coinciding of the anomaly zone to thermal occurrences.

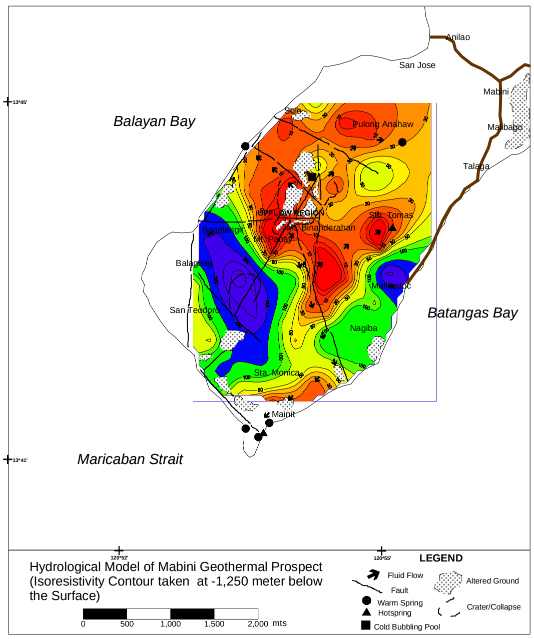

Figure 18: Hydrothermal Model of the Mabini Geothermal Prospect (Isoresistivity Contour taken at 1,250 Meter below the Surface).

6. CONCLUSION AND RECOMMENDATIONS

1. CSMT survey done in MBGP postulated the existence of geothermal resource beneath the Hulo Caldera Collapse. The interpreted geological sections from the several profile lines identified that the fault structures generally control the resistivity structure of the prospect. Although, this finding corroborate the earlier finding of PNOC-EDC on the existence of hydrothermal resource upwelling in Mt. Binanderahan, the results is still premature and may not be conclusive due to lack to comprehensive geophysical and drilling studies to be used as basis for correlation. Geophysical studies done in the area consist of short dipole, gravity, magnetics and soundings were meager and cover mostly few stations.

2. Based on the results, a follow up and detailed CSMT survey is recommended to be done in the area to better understand the nature of the hydrothermal system in Mabini. Areas targeted for the survey were the northern and immediate vicinity of the collapse. This to gain knowledge on the Pulanglupa anomaly in the north and to characterize furthers the resistivity structure of the caldera complex.

3. CSMT survey is indeed cost effective and ideal for short-term geothermal prospecting. However, some minor modification must be done on the method to maximize its utilization. Geothermal prospects commonly occurs in complex geologic environment wherein 2 or 3-D structures such as faults surely exists, the scalar measurement ability of CSMT makes it insensitive to these structures. To be able to compensate this shortfall, a Hy or Hz must be incorporated in the method. On the processing aspect, the data that was recently gathered and soon to be collected must be subjected to 2D or 3D inversion to better understand the complex geological nature of the prospect.

7. ACKNOWLEDGEMENT

The authors would like to thank the following persons who made the survey a success:

The Department of Energy through our Bureau Director Alicia N. Reyes for allowing us to conduct the survey; Mr. Asahi Hattori, our Japanese consultant; Local government unit of the Mabini town for logistic support; former Geothermal Division staff of the DOE for helping us in the data collection; and to our family who constantly pray for our safety and understand the nature of our work.

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