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Conceptual Model of Mt. Natib Geothermal Area as Revealed by Electromagnetic and Drilling Data

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ABSTRACT

Interest in the geothermal development of the Mt. Natib geothermal area in Bataan Peninsula in the Island of Luzon begun in 1987 by the then PNOC-EDC (now EDC). Based on the results of the surface geoscientific investigation in an area of about 850 km², two (2) exploratory wells were drilled within the Natib Collapse Caldera.

Well Na-1D was drilled to a depth of 2751.5 mVD (2859.0 mMD) with highest measured temperature of 282ºC at the bottom of the well. Due to low permeability of the structures encountered, the well did not discharge.

Well Na-2D reached to a total depth of 2916.12 mVD (3353.7 mMD) with a maximum measured temperature of 270ºC at 2916.28 mVD (10 days shut). Three discharge attempts were made in this well and proved to be unsuccessful.

Post-drilling geoscientific evaluation indicated the presence of exploitable hydrothermal system in Mt. Natib geothermal area. Hence, additional electromagnetic surveys such as CSMT and MT measurements were conducted in 2011 and 2018, respectively.

Both CSMT and MT surveys results revealed the presence geothermal resource further E-SE of Na-1D towards the Mt. Natib and Natib Crater structure. The updated geothermal resource estimate based on MT, CSMT and drilling data, range from 33 MWe (P90) to 77 MWe (P50).

1. INTRODUCTION

Mt. Natib geothermal prospect is located in the Bataan Peninsula (Figure 1) in the Island of Luzon. It is approximately 60 km WNW of Manila or 110 km by road. In 1987, PNOC-EDC (now EDC) conducted surface geoscientific investigation in an area of about 850 km² covering Mts. Natib and Mariveles in the northern and southern part, respectively, of the prospect area. Based on the results of these studies, two (2) exploratory wells were drilled within the Natib Caldera.

Well Na-1D was drilled to a depth of 2751.5 mVD (2859.0 mMD) with highest measured temperature of 282ºC at the bottom of the well. Due to low permeability of the structures encountered, the well did not discharge.

Well Na-2D reached to a total depth of 2916.12 mVD (3353.7 mMD) with a maximum measured temperature of 270ºC at 2916.28 mVD (10 days shut). Three discharge attempts were made in this well and proved to be unsuccessful.

Post-drilling geoscientific evaluation indicated the presence of exploitable hydrothermal system in Mt. Natib geothermal area. It was recommended that additional electromagnetic measurements be conducted within the Natib Collapse Structure and to the eastern side toward Natib Crater where several parasitic Andesite Domes are present.

On May to July 2011 a controlled source magnetotelluric (CSMT) survey was carried out by Clean Rock Energy Corporation and MT measurements on the first quarter of 2018 by 3J Tech. With the addition of these new data, a revised conceptual model is presented in this report.

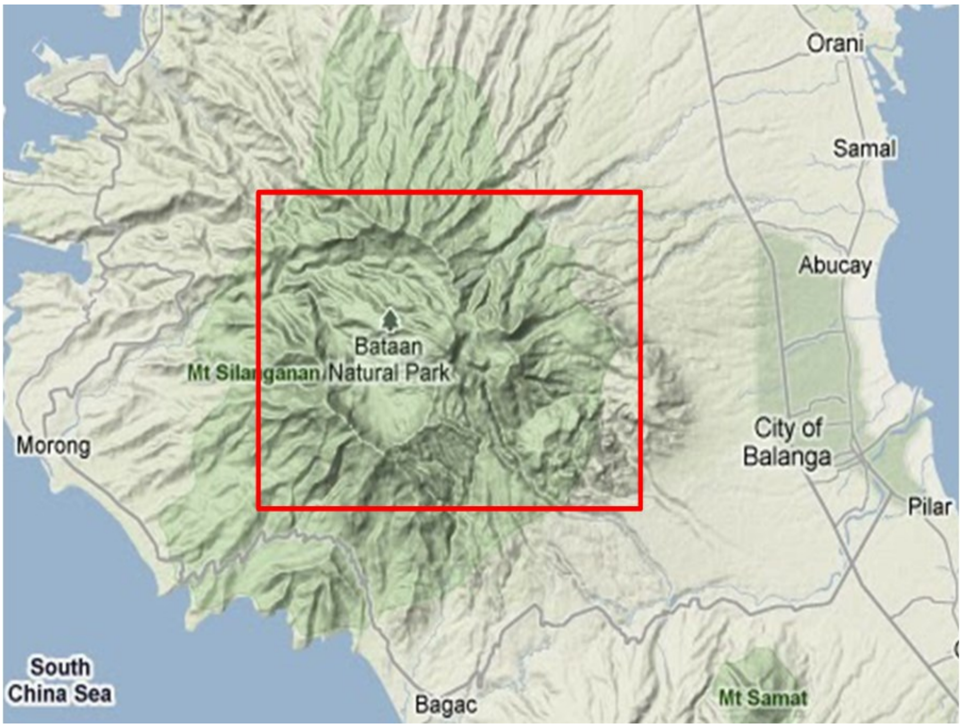

Figure 1: Location map of Mt. Natib Geothermal Prospect.

2. POST-DRILLING HYDROTHERMAL MODEL

Geological evidences favor the existence of a geothermal system in Natib. The heat source may be related to Pleistocene to Holocene resurgent volcanism, expressed as andesitic domes, on the eastern rim of the Natib Caldera (Figure 2). Based on geomorphology, the absence of the surface alteration, and by comparison with dated parasitic cones, these domes, e.g., Mt. Natib, are probably 500,000 years old (Panem 1988). The latest pyroclastics in the vicinity were deposited 30,000-100,000 years ago. The near-vertical NW-SE and nearly E-W trending faults allow the preferential upward movement of fluids, as evidenced by the close association of these structures with thermal features. However, the low flows of the thermal springs (<1 liter/sec) suggest limited near-surface permeability.

The Natib Caldera walls acts as a barrier to horizontal fluid flow, as implied by the localization of the most impressive thermal manifestations within a 23 km2 area inside the caldera (Figure 2).

Only secondary thermal springs occur in Mt Natib. The hot spring waters at higher elevation are enriched in SO4 and HCO3, signifying the formation of a condensate, and the collapse of the steam column. Due to the limited permeability along the vertical structures, these condensate layers percolate downwards, and mix with the inferred primary alkali-chloride geothermal water. With the addition of cold meteoric water, these form the SO4 –HCO3-C1 waters that are prevalent in the area.

The widespread deposition of travertine and iron hydroxides associated with the thermal springs, as well as the absence of solfataras, fumaroles, high gas manifestations, and silica sinters in Natib suggest low subsurface temperatures.

Based on geological evidences, the upflow area in the Mt. Natib geothermal prospect is located in the highlands, proximal to the Mt. Natib dome. Outflow is towards the lowlands, where Bisay and Uyong are located in the northwest, and Tawawa in the west.

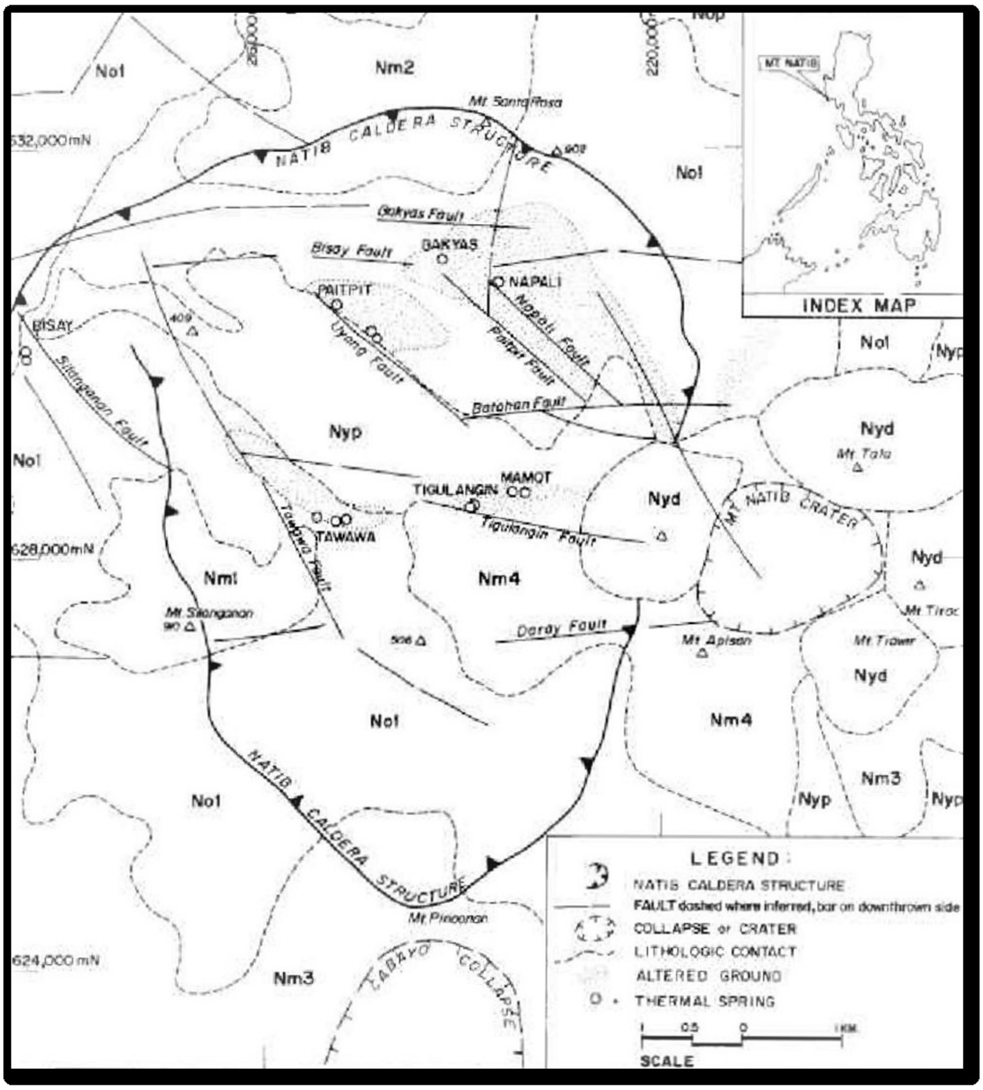

Figure 2: Geological Map of Mt. Natib Geothermal Project.

3. CONTROLLED SOURCE MAGNETOTELLURIC SURVEY (CSMT)

The CSMT data are presented as stitched 1-D model along NW-SE profile line (Figures 3) and as elevation contour map of the base of the conductive layer or top of the reservoir (Figure 4).

In Figure 3, the top most layers are characterized by the presence of about 450 meters thick resistivity body with 96 - 280 ohm-m values. This layer is underlain by a highly conductive zone with resistivity values ranging from 6 to 10 ohm-m that was observed from CSMT stations C9 to J2 and terminates at station J3 between Mt. Natib and Mt. Tiawir. Furthermore, this conductive clay cap is dipping to the northwest towards the location of the known surface thermal manifestation and well Na-2D. Well Na-1D was drilled where the base of the conductive layer is at shallowest elevation. This model is typical of a high relief geothermal system (Anderson and Usher, 2005).

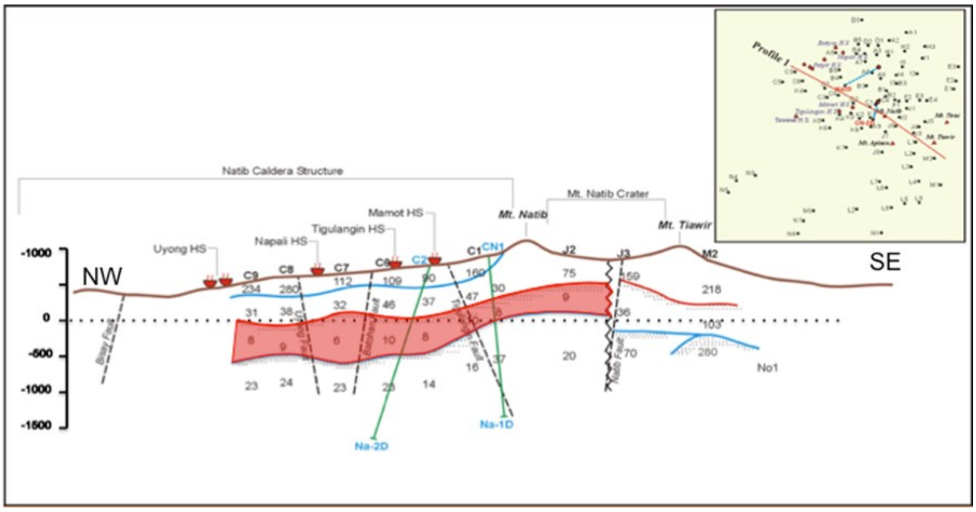

Figure 3: Resistivity Model by CSMT Along NW-SE Trending Profile Line.

Figure 4 shows the elevation of the base of the conductive layer. The -800m contour was interpreted to represent the size and configuration of the geothermal resource. Several northwest – southeast trending structures can be correlated to this elevation contour map of the base of the conductive layers. Well Na-1D is located inside this -800m contour anomaly while the bottom of well Na-2D was drilled outside of this. Based on this pattern, it appears that the upflow region is somewhere below the south-southeastern slope of Mt. Natib, hence, Na-1D was drilled near or at the edge of the upflow zone while Na-2D was drilled in the outflow zone.

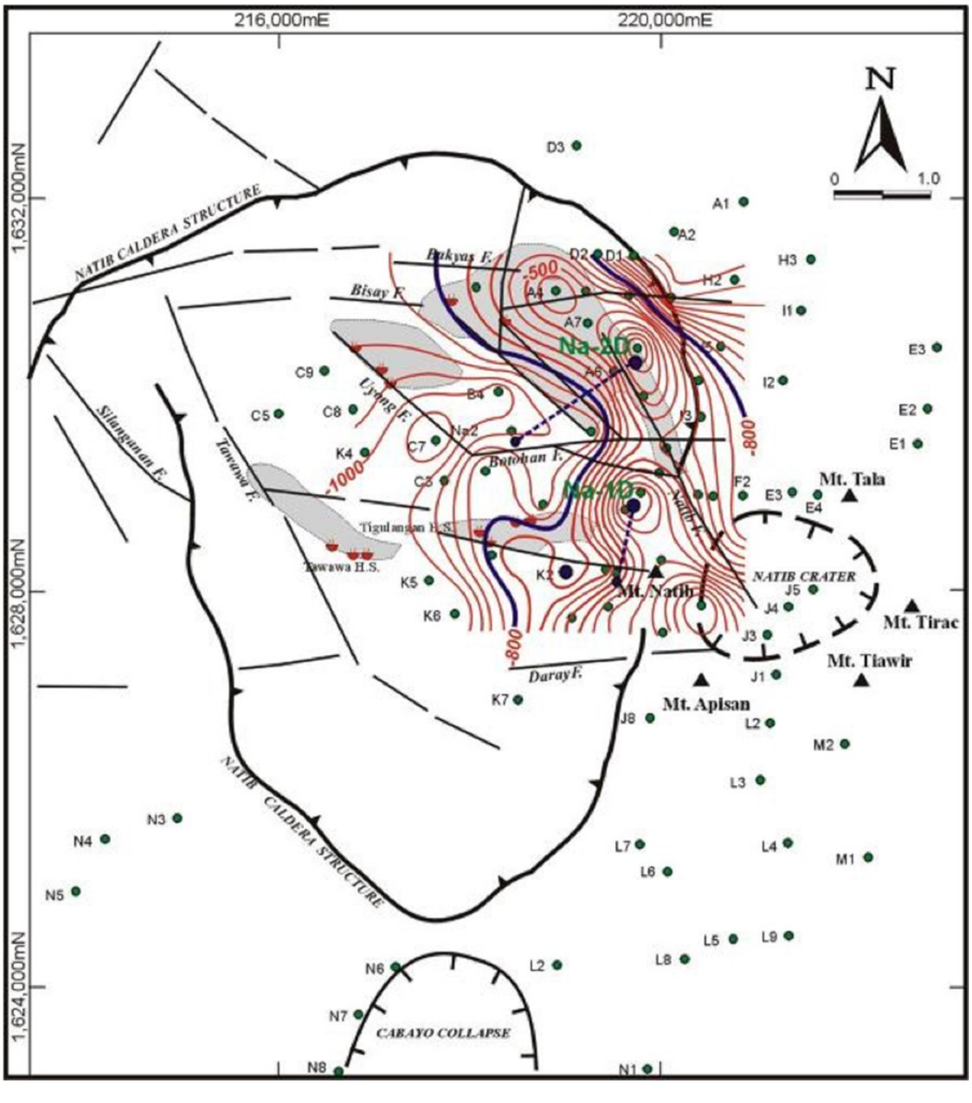

Figure 4: Elevation Contour of the Base of the Clay Cap from CSMT. The shallowest occurrence of the base of the clay is located southeast of Mt. Natib and deepest to the northwest toward the thermal manifestation along Uyong Fault.

4. MAGNETOTELLURIC SOUNDING MEASUREMENTS

Further resistivity measurements were carried out using the magnetotelluric (MT) method in 2018 by 3jtech of Taipei. The survey aims to validate the result of the CSMT survey. A total of 58 MT sounding stations were occupied and measured, located mostly on the same CSMT survey area.

Figure 5 exhibits the outline of the possible geothermal reservoir as represented by the yellow polygon and termed as Natib Anomaly. The northwestern half of the anomaly is located inside the Natib Caldera Structure that encloses the known surface thermal manifestation and the two (2) wells drilled, Na-1D and Na-2D. On the other hand, the southeastern side encloses several volcanic centers and partly the southern part of the Natib Crater.

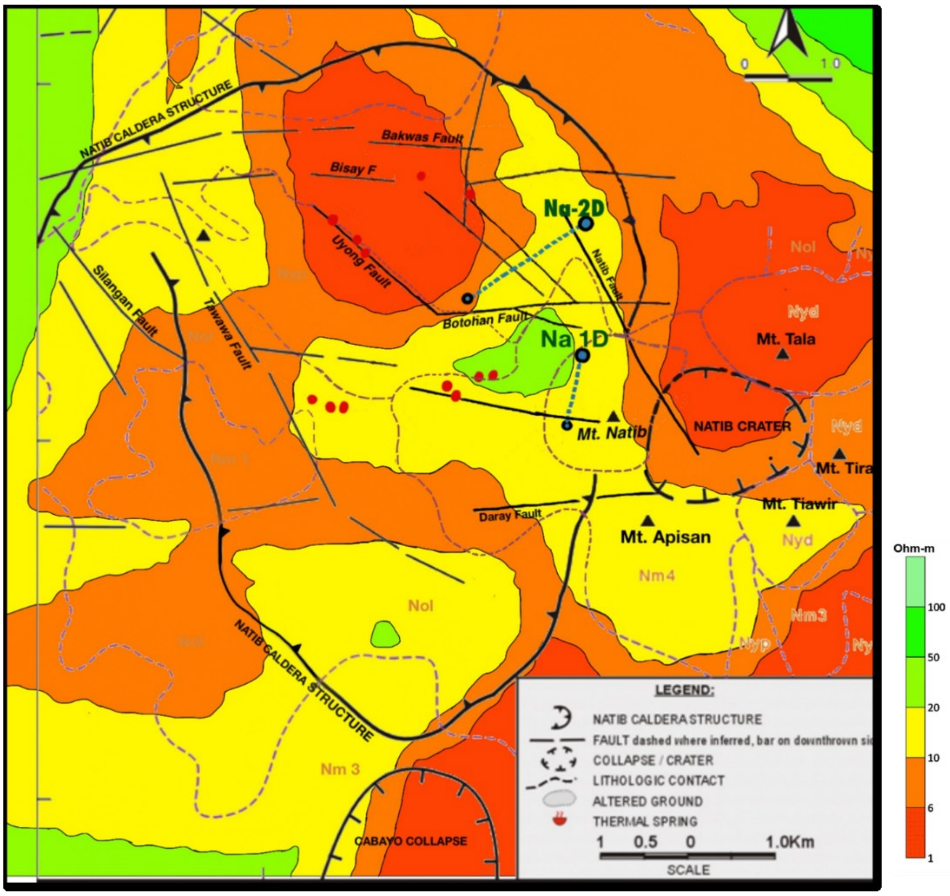

Figure 5: Isoresistivity Map at 2,000 meters Depths Overlain in a Geological Map.

The shallowest occurrence of the top of the reservoir or the Natib anomaly was mapped at about 650 meters below sea level on the south-southeast of Mt. Natib Crater (Figure 6). It was also in this area were the bottom of well Na-1D was terminated. Since limited fault structures were found in this southeastern portion of the anomaly, LiDAR mapping must be conducted in this area prior to pursuing further drilling activities.

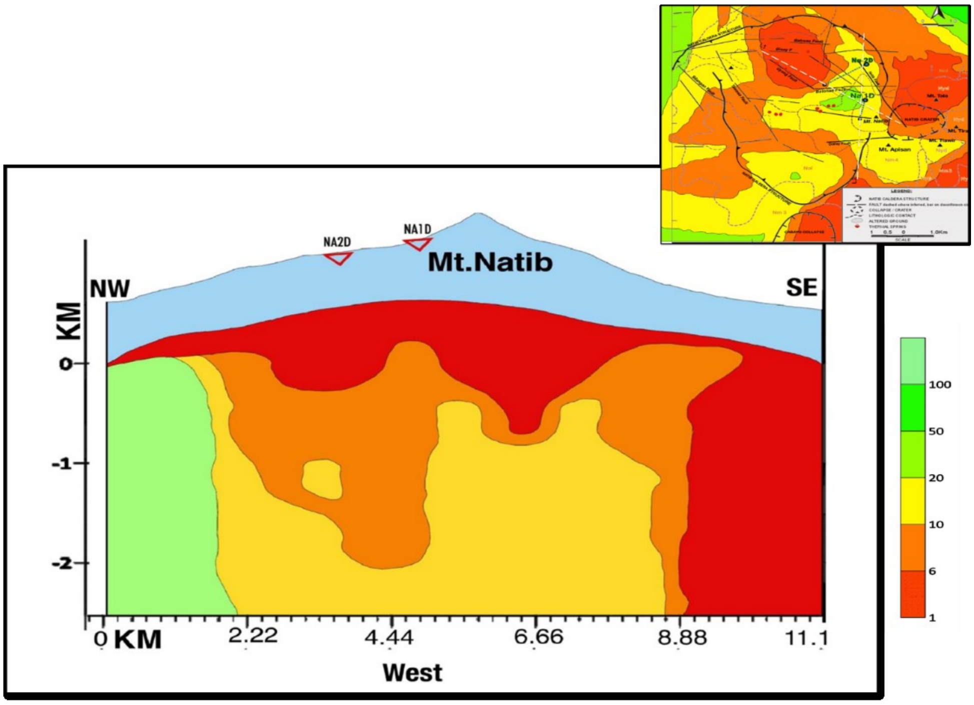

Figure 6: Resistivity Model Along Line-1. Location of the Profile Line is Shown on the Upper Right Corner of the Map. Bar Code Represent Resistivity Values of Various Layers.

5. GEOPHYSICAL MODEL

The geophysical model of Mt. Natib Geothermal Project was constructed on the basis of the results of CSMT and MT surveys correlated with drilling data. The model, as shown in Figure 7, reveals the presence of an exploitable geothermal resource.

The upflow is located on the south-southeast slope of Mt. Natib Crater and preferentially outflowing to the northwest towards well Na-2D and to the known surface thermal manifestation. Well Na-1D was bottom-out inside or at the edge of the supposed geothermal reservoir, while, well Na-2D was drilled in an outflow region. It is speculated that the heat source is associated with Mt. Natib Crater.

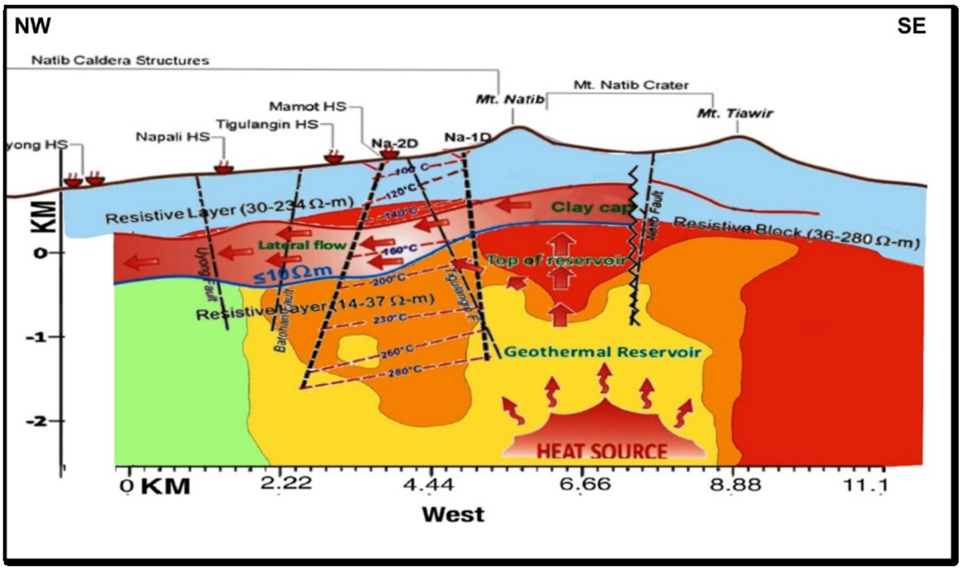

Figure 7: Postulated Geophysical Model as Revealed by CSMT and MT Survey and Drilling Data.

6. RESOURCE ESTIMATE

The energy reserve estimate of the MT anomaly defined by the isoresistivity map at 2,000 meters depths in Figure 5 is in the range of 33 – 120 MWe as shown in Figures 8 & 9.

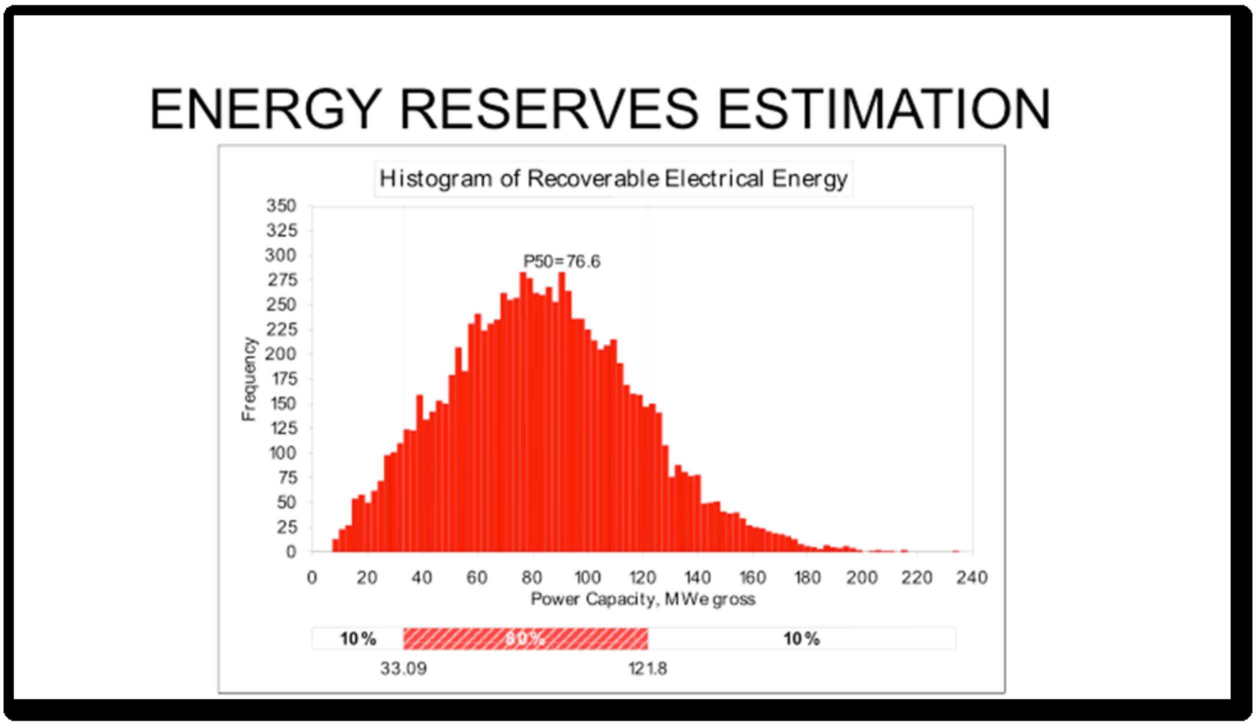

Figure 8. Histogram of Recoverable Energy, P90 = 33 MWe, P50 = 76.6 MWe and P10 = 122 MWe.

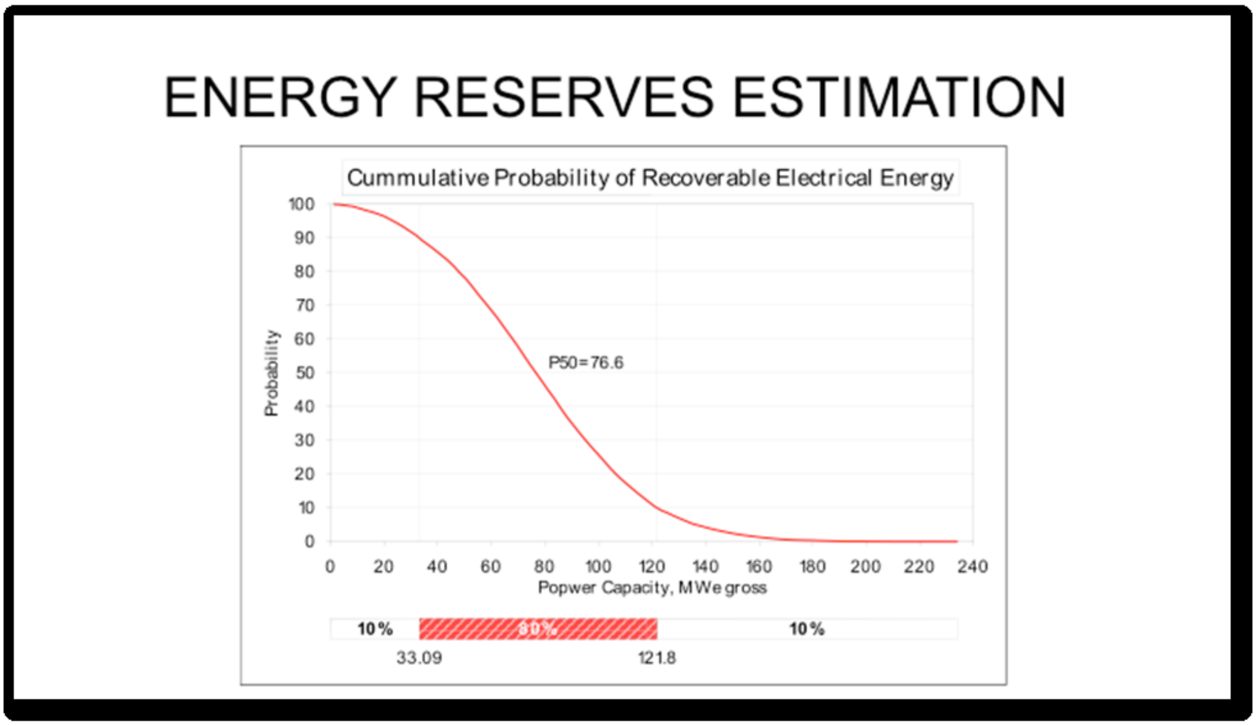

Figure 9. Cumulative Probability of Recoverable Electrical Energy.

7. CONCLUSION AND RECOMMENDATION

Drilling results indicate the presence of geothermal resource with maximum measured temperature of 282°C and with an issue on permeability.

Electromagnetic surveys confirmed the existence of geothermal system in Natib. The heat source may be related to Pleistocene to Holocene resurgent volcanism, expressed as andesitic domes, on the eastern rim of the Natib Caldera.

The close agreement of the results of the CSMT and MT surveys further enhanced the presence of exploitable geothermal resource in the project.

The estimated geothermal resource based on MT, CSMT and drilling data, range from 33 MWe (P90) to 77 MWe (P50).

Since limited fault structures were found in the southeastern portion of the anomaly, LiDAR mapping must be conducted, followed by detailed structural study prior to pursuing further drilling activities.

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