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Geophysical Model Update of the Kamojang Geothermal Field, Indonesia

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ABSTRACT

The Kamojang Geothermal Field is a vapor dominated system. It is located in West Java, Indonesia, with a generation of 235 MW from five power plant units. The Kamojang geothermal field has been operating for 35 years. Several geosciences surveys were carried out to understand better reservoir conditions, especially geophysical surveys. From the early phase of exploration around the 1970s to the exploitation and development phase, several geophysical surveys were conducted, such as DC resistivity, Geo-Magnetic, CSAMT, Gravity, MT, MEQ, Sonic and resistivity logging. The new information obtained from geophysical surveys is integrated with drilling data such as drilling cutting, coring, P & T survey analysis, production log. This new information aims to update the geophysical model and reservoir characterization.

1. INTRODUCTION

The Kamojang Geothermal Field, which is located in the southeast of Bandung or in the northwest of Garut, with a 25 km distance. The Kamojang Geothermal Field is the first geothermal field that was explored and developed in Indonesia. This field is one of the Geothermal WKP owned by PT Pertamina Geothermal Energy. Since the utilization of the geothermal energy into electricity in 1983, the Kamojang Geothermal Field has reached the operating age of 36 years. The current installed capacity is 235 MW, from five Geothermal Power Plants (GPP), comprised of Unit 1 (30 MW); Unit 2 (55 MW); Unit 3 (55 MW); Unit 4 (60 MW) and Unit 5 (35 MW). For the production of 235 MW, steam of about 1645 tons per hour is supplied from 58 production wells, which are distributed in an area of approximately 23 km^2.

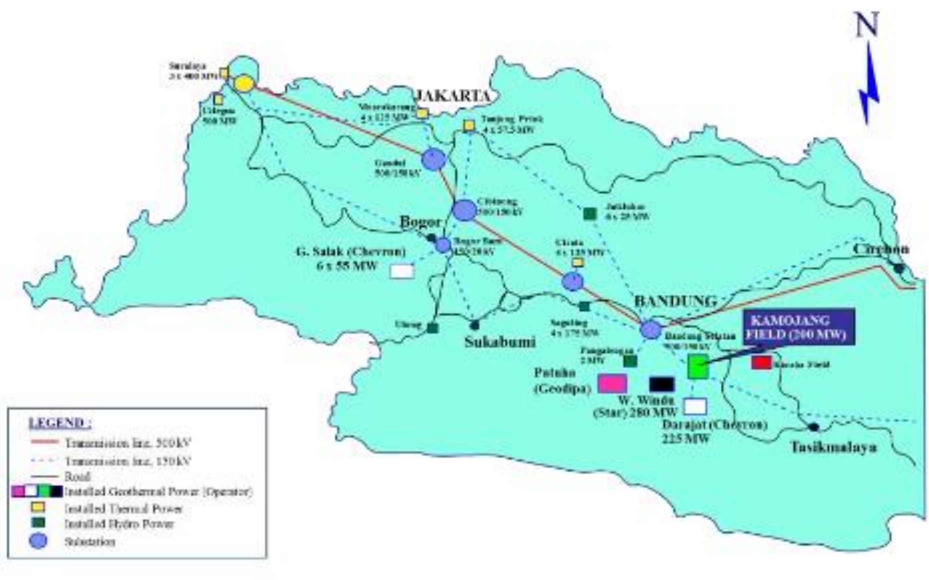

Figure 1. Kamojang and another west java geothermal area map

2. GEOLOGICAL SETTINGS

Kamojang is located at the Rakutak Guntur volcanic sequence. It is a product of quaternary volcanic activity series (Figure 2). The sequence indicates the evolution of younger volcanic activity towards the northeast (Pertamina, 1995). In those volcanic series, the two important faults are the Kendang fault and the Citepus fault. Moreover, Kamojang is located in the Pangkalan depression fault that forms a sort of cover that is ideal for the formation of dry steam geothermal systems. As expected, the formation of a vapor-dominated geothermal system begins with a specific geological setting where there is a permeable reservoir and an impermeable recharge area.

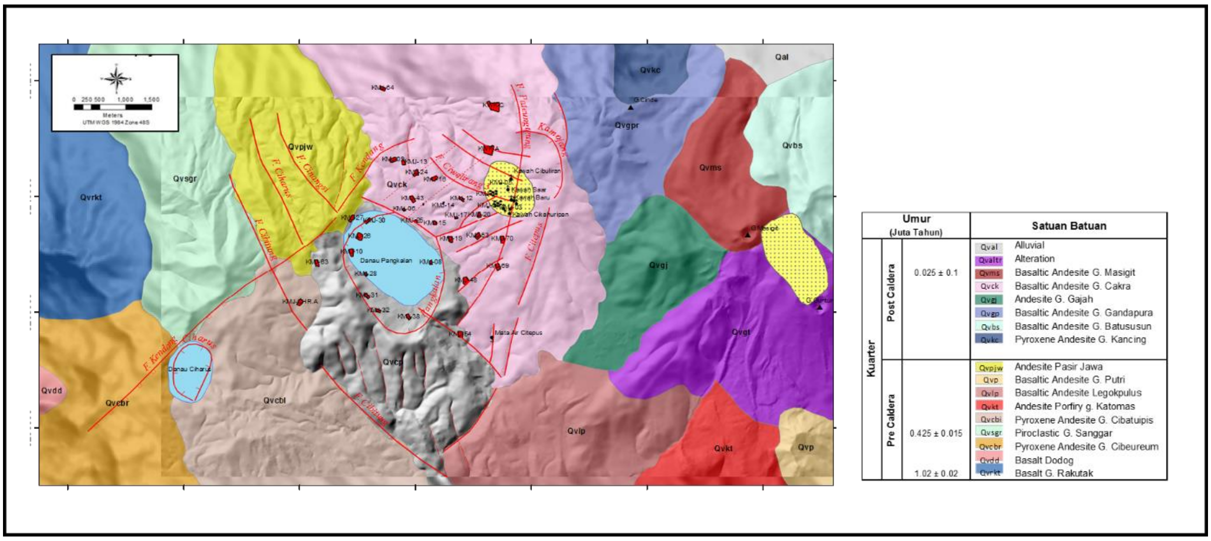

Figure 2. Regional geology map of Kamojang

3. THE MAGNETOTELLURIC DATA

A magnetotelluric (MT) survey at the Kamojang geothermal field, was conducted in several MT survey campaigns. These stations were the 18 MT station (2005), the 22 MT station (2008), the 22 MT station (2009), and the 75 MT station (2015) with spacing station ±1-1.5km (**Figure 3**). MT data were processed by a 3D inversion with topography (by CGG Electromagnetics) with a grid size (xyz) of 175 x 175 x 25 m. The 3D inversion modeling by CGG Electromagnetics Italy in 2014-2015 used a Finite Integration technique (FIT), the topography included in the modeling.

Vectors represent complex ratios of vertical to horizontal magnetic field components. Induction arrows can be used to infer the presence or absence of lateral variations in conductivity. In the Parkinson convention, the vectors point towards anomalous internal concentrations of current (Parkinson, 1959). Induction arrows maps show conductive zones pointed by induction arrows located in the Pangkalan area (center of Kamojang Geothermal Field) and also at the Cilutung and Cakra Gandapura complexes (Northeast Kamojang). (**Figure 3**).

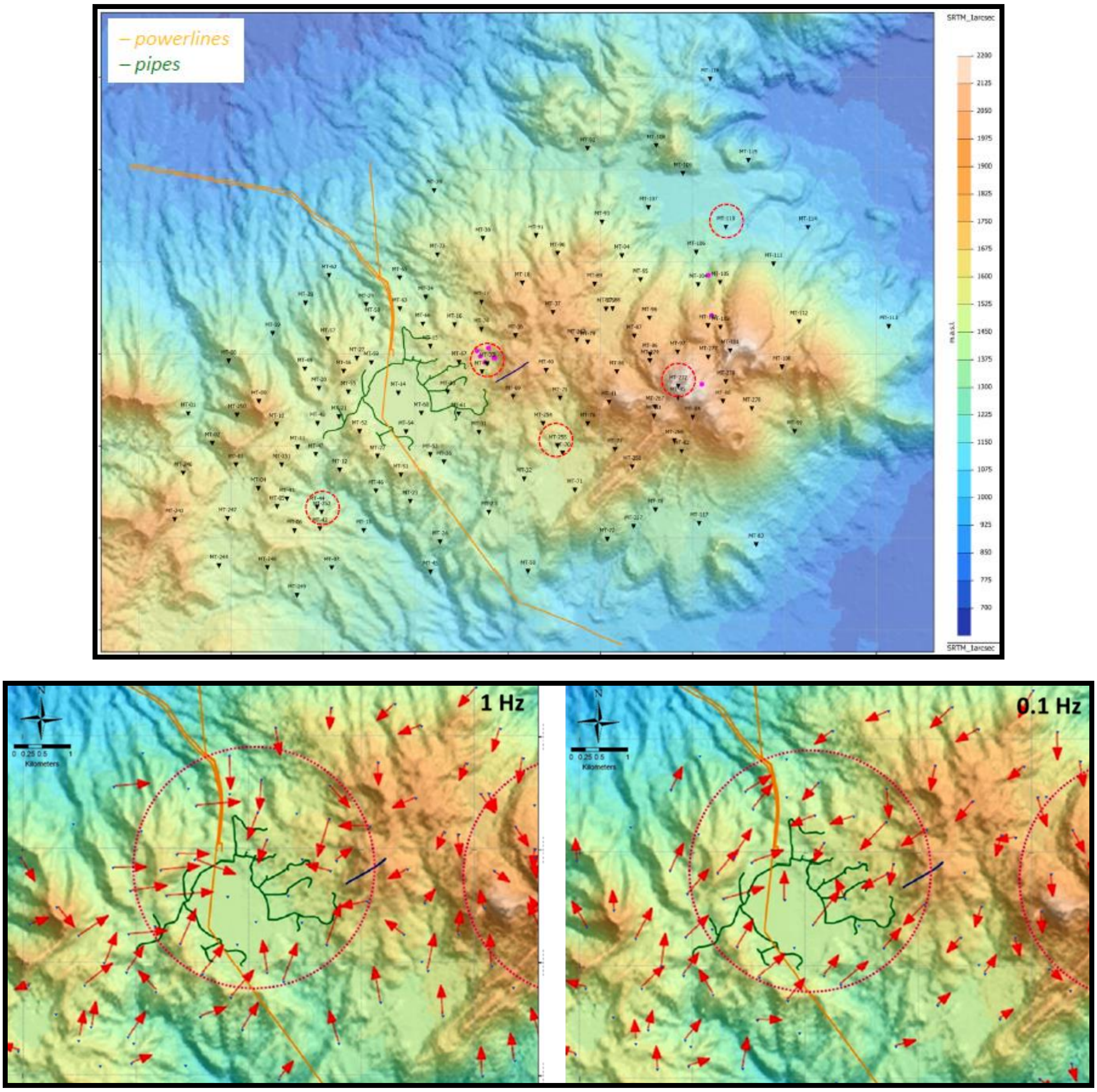

Figure 3. MT Station distribution (top) & Induction Arrow Maps (bottom)

Figure 4 shows a phase tensor plot of MT data at Kamojang with a frequency of 30 Hz, 3 Hz, 0.3 Hz, and 0.03 Hz. The value of the phase tensor can be associated with the presence of a resistive/conductive zone. The direction of the ellipse produced by the phase tensor value is able to show the dominant strike direction in the MT measurement area. The phase tensor at the frequency of 30Hz shows that there is a high phase value shown in a reddish color. This can be seen in the high phase value located in the Pangkalan Area (center of Kamojang field) and in the Cakra Gandapura and Masigit area (North East of Kamojang field). Low phase value located near the Ciharus area (South West Kamojang field). From the results, phase tensor at frequencies of 0.3Hz and 0.03Hz shows a low phase value (blue color). An ellipsoid from the phase tensor shows the dominant geoelectric strike slope direction in this area is NW-SE direction with ambiguity 90^o from the ellipsoid phase tensor.

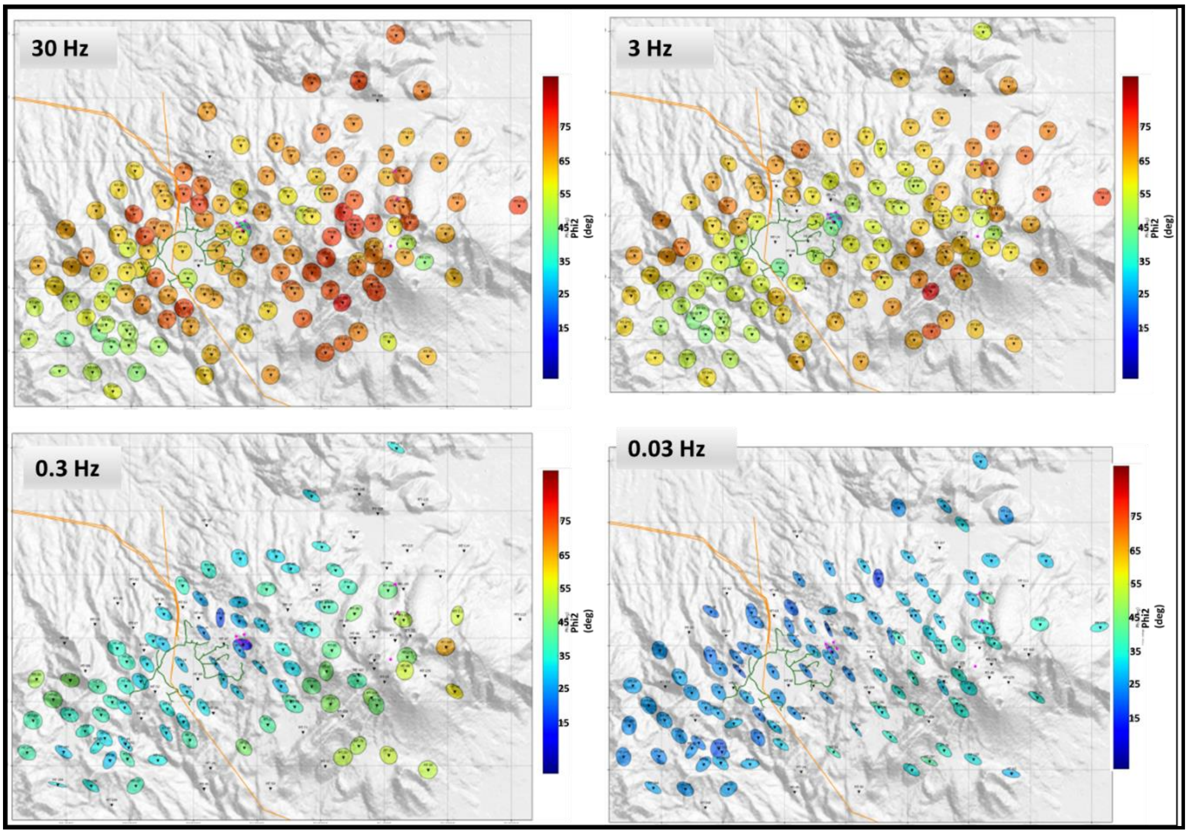

Figure 4. Phase Tensor Maps

Magnetotelluric modeling has shown, at several shallow elevation slices, a widespread conductor act as reservoir caprock and less that continue to the South-West at the Ciharus area (**Figure 5**). The correlation between the Methylene Blue Test (MBT) data and the MT section shows that the bottom cap rock correlates with a resistivity value < 12 ohm.m. Sub resistive zones show trending in the NE-SW direction with a range of 40-70 ohm.m interpreted the expression of propylitic signature that acts as the host of the geothermal reservoir. The zone covered by the conductor (impressions of Caprock) with a resistivity value <12 ohm.m. Up doming features represent a reservoir zone at the Kamojang geothermal field, this is shown clearly in the 3D resistivity model, especially in NW-SE vertical section. In the upper of up doming features shows a dashed line with a low resistivity value. This was representative of the argillic zone and contains smectite clay based on lithology data. This zone is shallower in the center of the section compared to other sides (**Figure 6**).

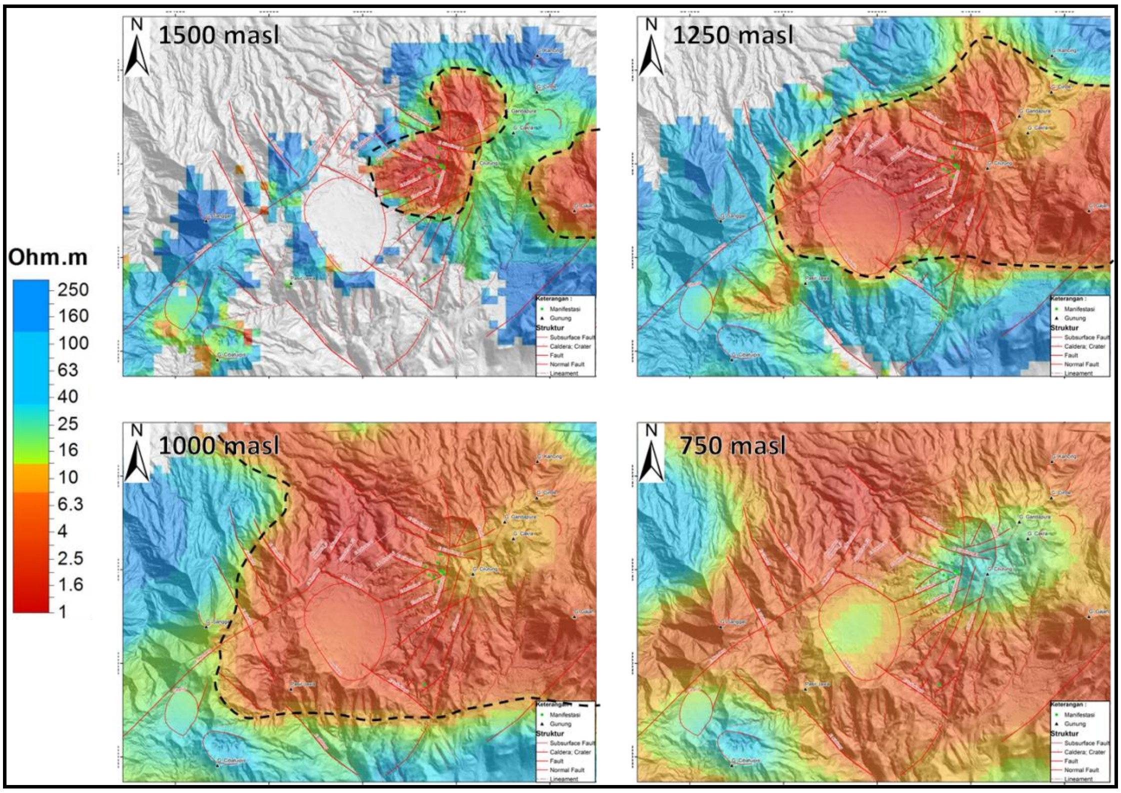

Figure 5. Reservoir Cap rock identification at the Kamojang geothermal field

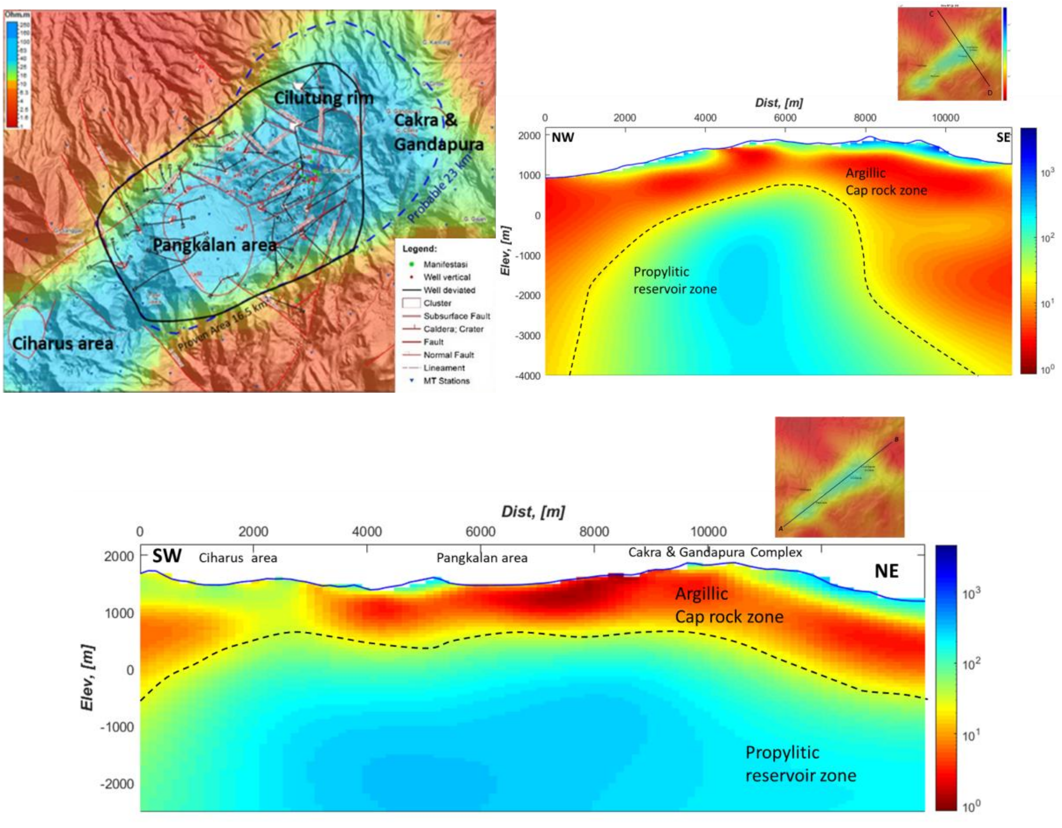

Figure 6. MT Map and section shows prophylitic and caprock zone

4. THE GRAVITY DATA

A gravity survey was conducted in 1997 using a Lacoste Romberg G653 and in 2016 using a Scintrex CG-5 in 176 acquisition stations. Both gravity data (1997 and 2016) were reprocessed using the same parameter (with rho=2395 kg/m^3, using parasnis & nettleton) and also converted using datum, zone and same projection system. Both the CBA gravity anomaly maps of 1997 and 2016 show a high gravity anomaly (37-38 mGal) around the southwest of the ciharus area and the pangkalan area (**Figure 7**).

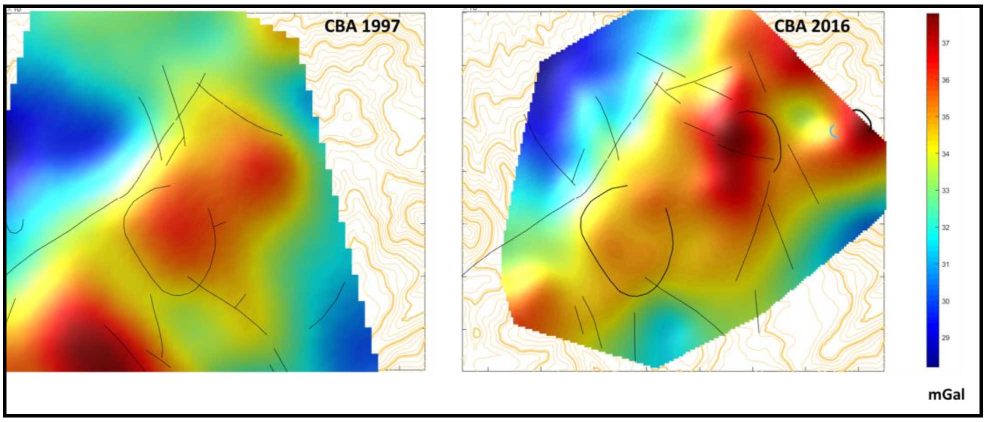

Figure 7. CBA Gravity map 1997 and 2016

The CBA Gravity Map 2016, shows the prospect of an anomaly in more detail because the acquisition station is denser than the 1997 acquisition and using a more accurate and precise gravimeter (Scintrex CG-5). The CBA Map 2016 (Figure 8) shows a high gravity anomaly located in the Pangkalan caldera, Cilutung rim, and Cakra & Gandapura complex. The highest gravity value located around the Cilutung rim area has a gravity value around 37-38 mgal. It's higher than the gravity value around the Pangkalan caldera by around 3-4 mgal. Eruption centers with circular features at the pangkalan caldera, cilutung rim and the cakra & gandapura complex show high gravity value. This indicates and interpret as an intrusive body beneath these areas and acts as a heat source at the Kamojang Geothermal Field.

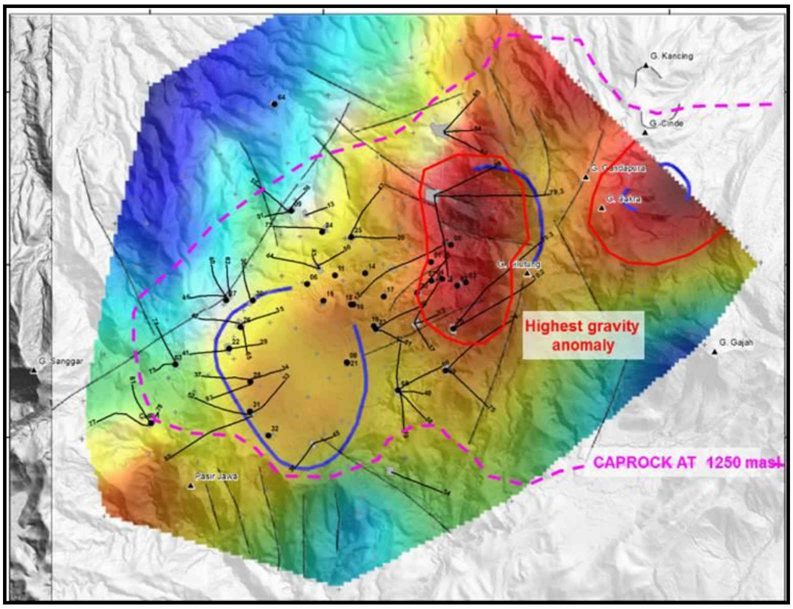

Figure 8. CBA Gravity Map 2016

5. THE MICROSEISMIC DATA

We present a Vp/VS model and our interpretation of the concept of geothermal of the Kamojang Geothermal Field. As validation of this tomography result, we show another geophysics method in the same slicing and section. Some display features are blanked considering those areas that were not covered by ray paths of P and S waves. Slice Vp/Vs ratios in elevation 0 msl (Figure 9) show a good correlation between model velocity Vp/VS and resistivity model. A low anomaly of VP/VS (<1.72) with trend direction to NE-SW is a related subresistive model (30-70 ohm.m) associated with propylitic reservoir zone. Meanwhile, the clay cap zone is related to a low value of resistivity with a resistivity value < 10 ohm.m and is correlated with high VP/VS (>1.74). Up doming features of the reservoir zone at the Kamojang field show clearly either in the VP/VS model or the 3D resistivity model (**Error! Reference source not found.**). In the upper of the up doming features shows a dashed line with a high VP/VS ratio (>1.74). This was representative of an argillic zone containing smectite clay based on lithology data.

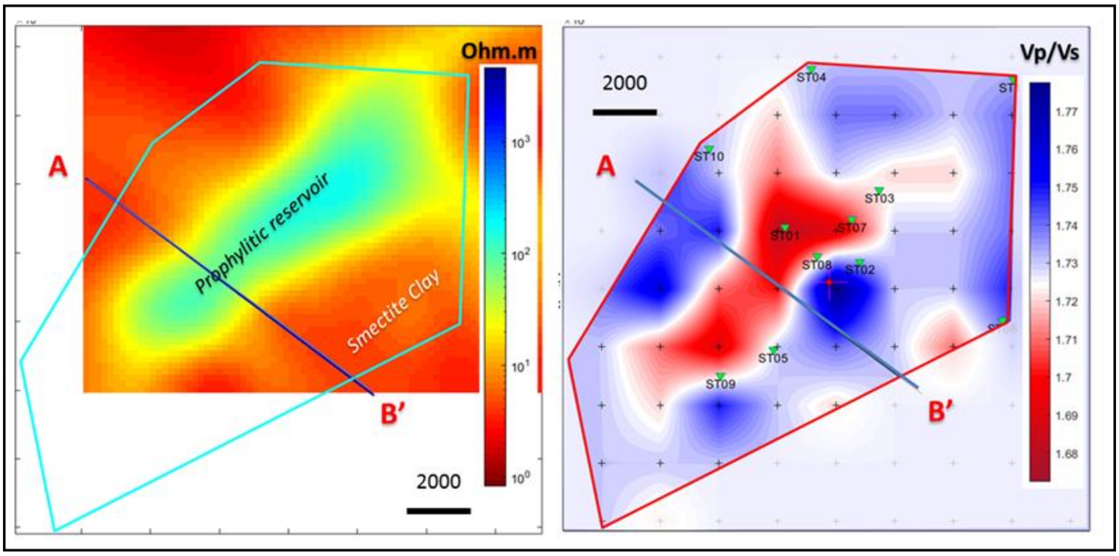

Figure 9. Resistivity map from 3D MT data (left) & Vp/Vs map from 3D tomography (right)

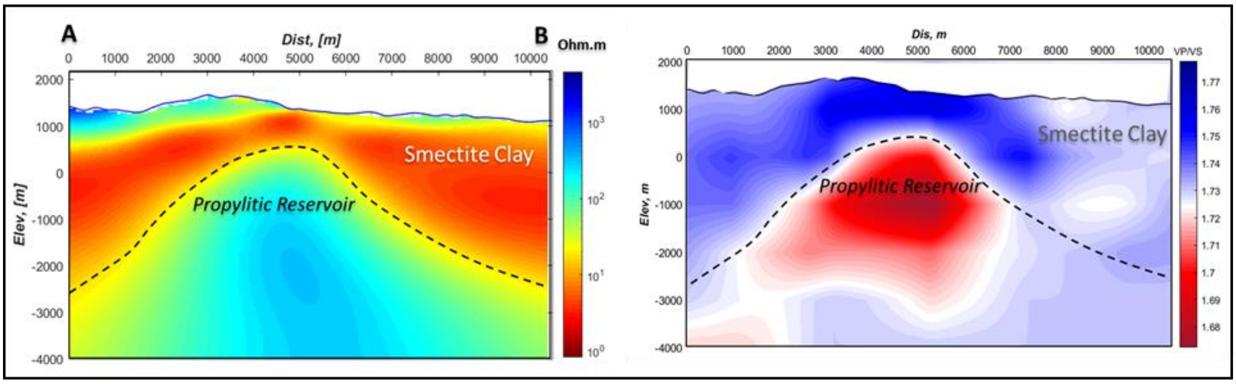

Figure 10. Resistivity section from 3D MT data (left) & Vp/Vs map from 3D tomography (right)

6. GEOPHYSICAL MODEL INTEGRATION

Based on some existing geophysical data, it can be interpreted that the geothermal system in Kamojang shows the spread of a propylitic reservoir zone with the NE-SW trend. It contains broadly expanding caprock zones covering the pangkalan caldera area, cilutung rim to chakra and gandpura complex, but not well developed at ciharus area. Based on gravity data, there are high gravity anomalies around the pangkalan, cilutung rim and cakra gandapura complex with the highest gravity around the cilutung rim. This phenomenon is interpreted as heat source extending from the pangkalan to the cilutung rim and chakra and gandapura complex with intrusive bodies shallower in the area of the cilutung rim and the cakra and gandpura complex. This is also supported by the P & T well data, where the reservoir initial temperature around the pangkalan area shows a high temperature around 230-235 °C. Also, the high initial temperature around the cilutung rim area has a temperature of around 230-235 °C. Geophysical models with the NE-SW section can be seen in **Figure 11**.

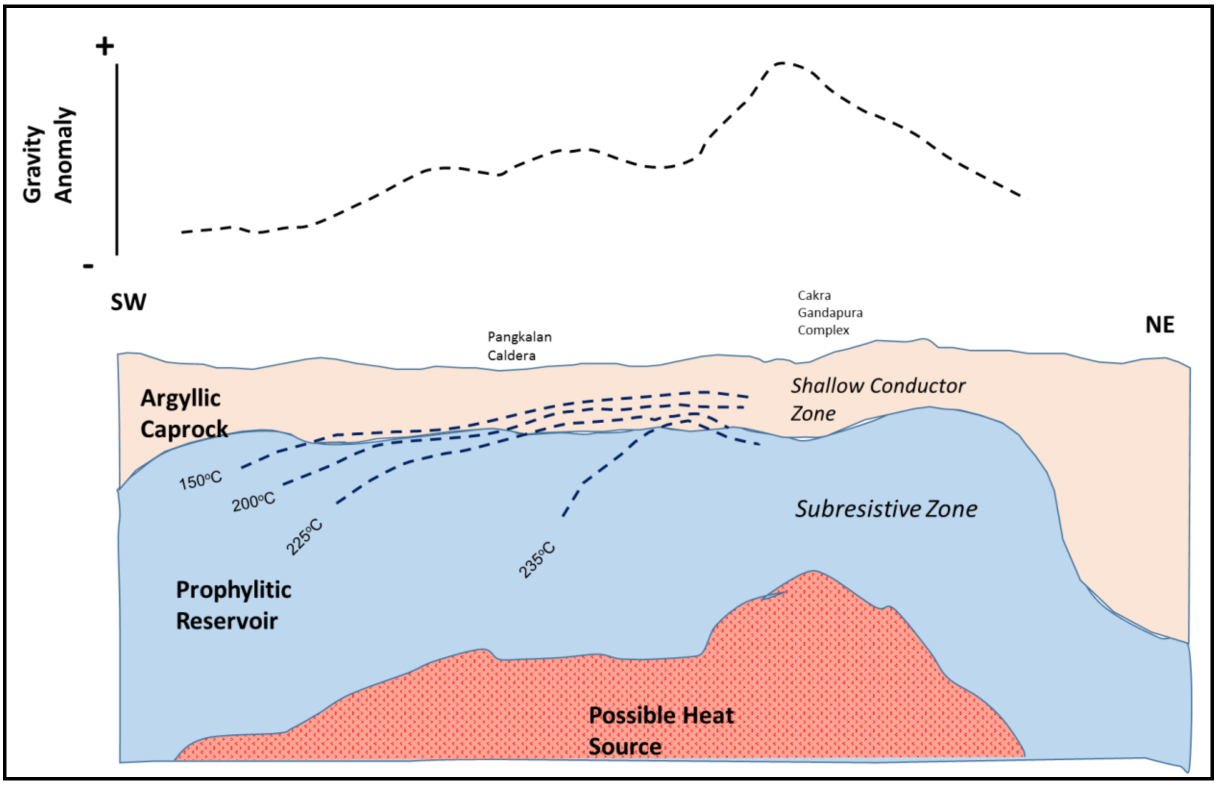

Figure 11. Geophysical conceptual model (lower panel), a section from NE to SW and its typical geophysical signatures(upper panels)

7. CONCLUSION

From the previous discussion, the author summarized all the geophysical update data in a conceptual geophysical model shown int the sketch of the figure. This represents an ideal NE-SW section across the Kamojang area. In summary, we can recognize the following features :

- MT data section shows that the caprock is well developed at Pangkalan through the Citung and Cakra Gandapura complex with up doming features shown in the Pangkalan and Cilutung area. Caprock is not well developed in the Ciharus area
- From MT slice we can see sub resistive zones shown trending in NE-SW with a range of 40-70 ohm.m that interpreted the expression of propylitic signature. This acts as the host of the geothermal reservoir. The zone covered by the conductor (impressions of Caprock) has a resistivity value < 12 ohm.m
- Gravity data shows a high gravity anomaly located at the Pangkalan caldera, the Cilutung rim and the Cakra and Gandapura complex interpreted as an intrusive body. These act as heat sources in these areas.
- Tomography data shows a good correlation between the model velocity Vp/VS and the resistivity model. The prophylitic reservoir zone associated with low Vp/Vs value with trending NE-SW and from the vertical section of Vp/Vs shows a caprock area associated with a higher Vp/Vs value.

REFERENCES

Armadillo, E., Rizzello D., Stimac Jim., 2014. The ARGeo geophysical model of the Tendaho Geothermal Field, Ethiopia.

Eberhart-Phillips, D., 1986. Three-dimensional velocity structure in northern California Coast Range from inversion of local earthquake arrival times, *Bull. seism. Soc. Am.*, **76,** 1025–1052.

Firmansyah, W., Sujarmaitanto, H., Mulyanto. 2013. Geochemistry Monitoring in the Kamojang Vapor-dominated Geothermal Field from 2010 to 2013. Proceedings World Geothermal Congress 2015.

Mujihardi, B., Widiyantoro, S., Nugraha, A.D., Structural Model of Kamojang Geothermal Field, West Java, Indonesia Based on Vp, Vs and Vp/Vs.

Sastranegara T., Hendriansyah T., Juanda A., 2019. Preliminary Result of Tomography Study at “Deltha” Geothermal Field for Identification Geothermal Characteristic Using Vp/Vs Ratio. Proceeding Joint Convention Yogyakarta.