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Magnetotelluric Reliability for Exploration Drilling Stage: Study Cases in Muara Laboh and Rantau Dedap Geothermal Project, Sumatera, Indonesia

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ABSTRACT

The most intriguing of exploring 'green' geothermal field is how reliable is collected data imaging subsurfaces real condition. Magnetotelluric (MT) capability to map distribution of low resistivity cly cap and to define geothermal reservoir geometry makes it as one of mandatory methods applied for assessing the resource potential and defining the exploration drilling strategy in Muara Laboh (ML) and Rantau Dedap (RD) geothermal fields. However, proving the reliability can be tough.

Geothermal resource delineation using MT method is about interpreting 1D, 2D and 3D MT inversion profiles generated from the data collected during the survey. The 10 ohm-m contour is used to map the base of conductive layer (BOC) which represents the base of clay cap. The BOC and chloride spring elevation are then used to constraint a construction of liquid boiling point to depth (BPD) curve. This approach is used to predict the top of reservoir (TOR) prior to drilling the first well, and help to create well design. In term of determining reservoir size, particular characteristics of conductive layers are being used to locate the boundary of reservoir.

Later, MT data reliability is evaluated with drilling data. At RD, 3D MT profile and predicted BPD are consistent with the drilling data. The TOR predited using MT is consisted with PT survey. However, in ML case, the 3D MT profile showgood correlation with clay cap distribution and reservoir geometry, but quite ambiguous in term of determining real TOR. Despite its limitation due to dimensional effect, static shifts and acquisition noise in the lower frequency, the utilization of 1D and 2D MT are considerably required as quality assurance check.

1. INTRODUCTION

Muara Laboh and Rantau Dedap geothermal fields are located related or adjacent to Great Sumatran Fault (GSF) which determined as a large strike-slip fault that affects volcanism along the south of Sumatera (**Figure 1**). Both geothermal systems are associated with stratovolcanos, composing of predominantly andesite lava and pyroclastic rock as well as breccia lava and sediments. The local structural play might different but strike-slip fault regime seems to control structural geology pattern in both fields. Muara Laboh has more complex structure geology having oblique divergent strike-slip fault regime that creates trans-tensional basin in the southern part of the field. While fault mechanism at Rantau Dedap is dominated by a strike-slip fault which is characterized by a dual slip involving simultaneous translation and extension. The deformation is dominated by oblique movement resulting from terminated strike-slip fault system.

Several scientific studies have been conducted during exploration stage in both fields. Magnetotelluric (MT) survey has been implemented before exploration drilling begins. The basic principle is that the low resistivity value (conductive layer) represents a clay cap overlying a geothermal system while high resistivity value (resistive core) is as assumed representing liquid reservoir. By then, the MT helps to delineate exploration area, providing a big picture of reservoir geometry.

2. USING MT PRIOR TO DRILLING

Using basic principle mentioned above, the base of conductive (BOC) layer (low resistivity value) picked from 1D and 3D inversion was collated to construct a BOC map. The trend and thickness of conductive layer is useful to predict reservoir doming feature, and together with the resistive core, can be used to "draw" the reservoir geometry. These features of low resistive layer and resistive core can delineate the potential productive area.

Naturally, in saturated pressure and temperature condition, liquid reservoir will boil and produce steam, the chloride spring elevation level represents reservoir liquid level. The gap zone between BOC and chloride spring level can be assumed a steam cap, or alternatively a low permeability cap consisting of mixed clay mineral such as an interlayered chlorite-smectite or interlayered illite-smectite as an effect of older hydrothermal system or phyllic alteration. If the BOC is deeper than the chloride spring level, it indicates compressed liquid reservoir or can be as worst as a non-productive reservoir. However, this only can be proven by drilling the wells.

Prior to drilling, predict the top of reservoir (TOR) is important to plan for a production casing setting depth. In green field, where there is no drilled well available, TOR can be predicted by constructing a boiling-point-to-depth curve based on BOC and the distributin of thermal features and their geothermometry (**Figure 2**). Based on the studies from the developed fields such as Salak, Darajat and Wayang Windu, the BOC is found to be correlating with temperature range 180-220°C. The BOC and the chloride spring level can be used as the starting point for the BPD curve which is then used to estimate TOR. Below the TOR, the temperature increase is calculated based on convective gradient temperature. The temperature used to define the TOR should be constraint by the geothermometry from the nearest manifestation.

The alteration assemblage distribution can also be predicted using this method. Low temperature mineral such as smectite, halloysite form a clay cap. As the temperature increases, the higher temperature mineral such as epidote, illite, wairakite and actinolite develop, which generally correlate with the resistive core.

All of the assessment mentioned above could be used to design the exploration well. The well trajectory shall capture the best opportunity to hit TOR and permeability target with appropriate inclination and azimuth. Especially if steam cap is predicted, well design shall be built by hit TOR before entry expected big permeability.

3. EVALUATING MT

3.1 Success Story

The 1D and 3D MT had been successfully applied in Muara Laboh and Rantau Dedap to delineate reservoir geometry. The overall clay cap geometry is well-represented by both 1D and 3D MT inversion profiles. Thickening and thinning pattern of low resistive layer value of 5 ohm-m corresponds with decreasing Methylene Blue Index (MEB) of less than 10, meaning the content of smectite-clay decreases as later confirmed by XRD analysis. Overall resistive core geometry is also well-pictured especially by 3D MT. The consistency between thinning-thickening low resistive layer and doming-plunging resistive core are also confirmed by the alteration mineral occurrence which represents clay cap and reservoir itself. The overall geometry delineated by MT matches with drilling result.

TOR prediction is well-predicted as drilling result proves. Although there is no exact match between pressure prediction and P-T survey data, there are similar trend of temperature pattern and almost the same depth of TOR prediction are proven by P-T survey from drilled wells. The resource boundary also well-predicted as it is represented by the thickening of low resistive layer where isothermal is likely flow downward in reservoir margin (**Figure 3** and **Figure 4**).

3.2 Ambiguity in 1D, 2D and 3D MT

Although low resistivity layers correlate with smectite clay as expected in Muara Laboh and Rantau Dedap wells, the base of smectite zone does not directly overlie >200°C permeable reservoir. Moreover, the clay cap appears to be discontinues in many 1D cross-sections, associated with surface geology suggesting that the clay cap consists of retrograde low argillic alteration of propylitic alteration exposed to the near-surface by erosion or sector collapse, a pattern commonly observed in Sumatra. In such environment, older rocks with relict alteration tend to prevent development of distributed permeability rather than area that have thicker recent volcanics. Despite these ambiguities, the extension of >230°C reservoir areas can be made based on MT resistivity and confirmed by well data.

The 1D inversion tends to exaggerate changes near discontinuities and to displace them because of dimensional distortion, while 3D inversion will smooths the low resistivity and makes the layers extend to depths greater than is shown by the 1D inversion. Both in Muara Laboh and Rantau Dadap case, the discrepancy of conductive layer in 1D inversion as shown in **Figure 3** and **Figure 4** may represent discontinuities, but in 3D inversion it tends to be a smooth layer. This becomes ambiguity especially to determine target for drilling.

In Rantau Dedap case and in earlier analyses of MT resistivity at Muara Laboh, based on the correlation with alteration in the wells, it is likely that the transition from high to low resistivity in the 1D inversion is likely to be closer to the transition from smectite to illite (or mixed layer) clay. However, also like at Rantau Dadap, the base of smectite clay is likely to be shallower than the top of the reservoir permeability at most wells drilled at Muara Laboh. That is, there is likely to be a moderate to high resistivity mixed-layer clay zone corresponding to a low permeability zone with a conductive temperature gradient below the smectite cap. This is characteristic of geothermal fields like Muara Laboh where much of smectite alteration at higher elevation has been removed by erosion or sector collapse, exposing higher rank alteration that is undergoing retrograde alteration. However, as at many other fields with this case, the resistivity pattern is more ambiguous but still probably indication of reservoir geometry.

3. CONCLUSION

MT can be used for exploration prior to drilling by concerning the distribution of low resistive and high resistivity layer, also overall resistivity pattern. However, MT cannot be a stand-alone method but it has to be combined with conceptual model (built by geochemistry and geological study). This combination is used to reduce the ambiguity and misinterpretation among geoscientists. Then, evaluating MT after drilling is recommended for future drilling plan.

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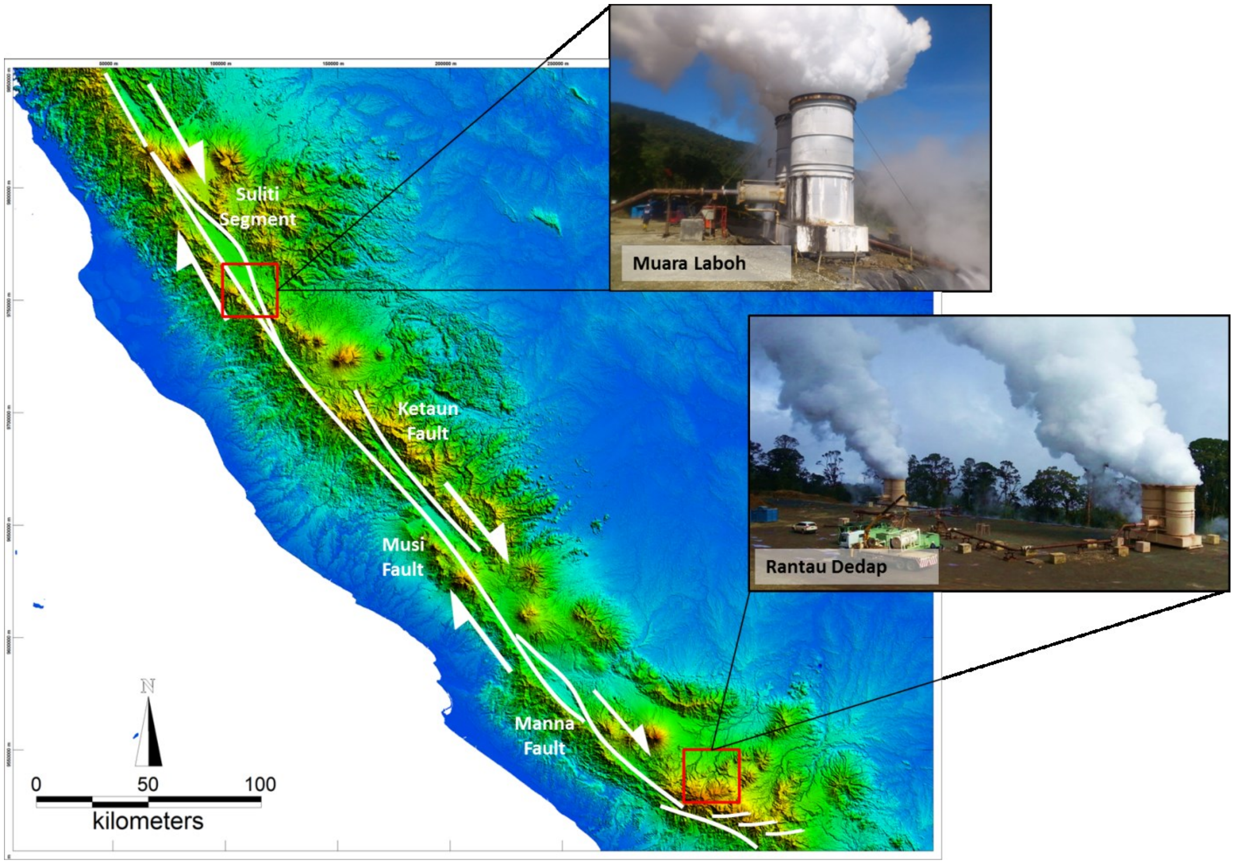

Figure 1: Muara Laboh and Rantau Dedap geothermal field location, related to Great Sumatran Fault along southern area. Muara Laboh might relate to Great Sumatran Fault and Rantau Dedap is off from the big fault.

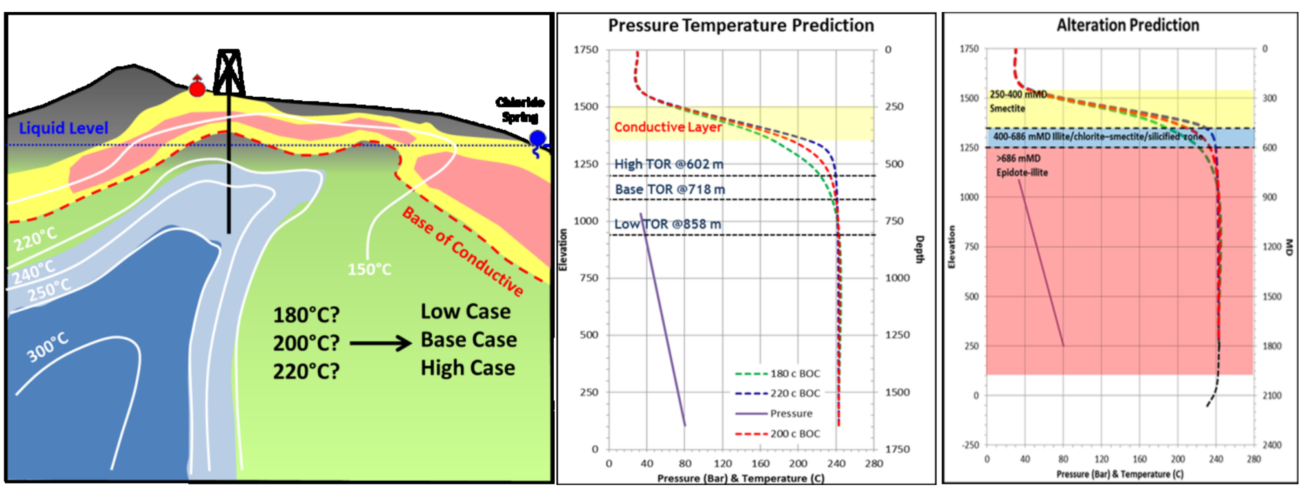

Figure 2: A schematic of typical resistivity pattern in high temperature system (modified from Cumming and Mackie, 2010). Pressure -temperature and alteration prediction method by boiling-point to depth, with chloride spring and base of conductive layer as basic point assumption. Conductive and convective gradient is controlled by chloride spring elevation (1350 masl in this figure).

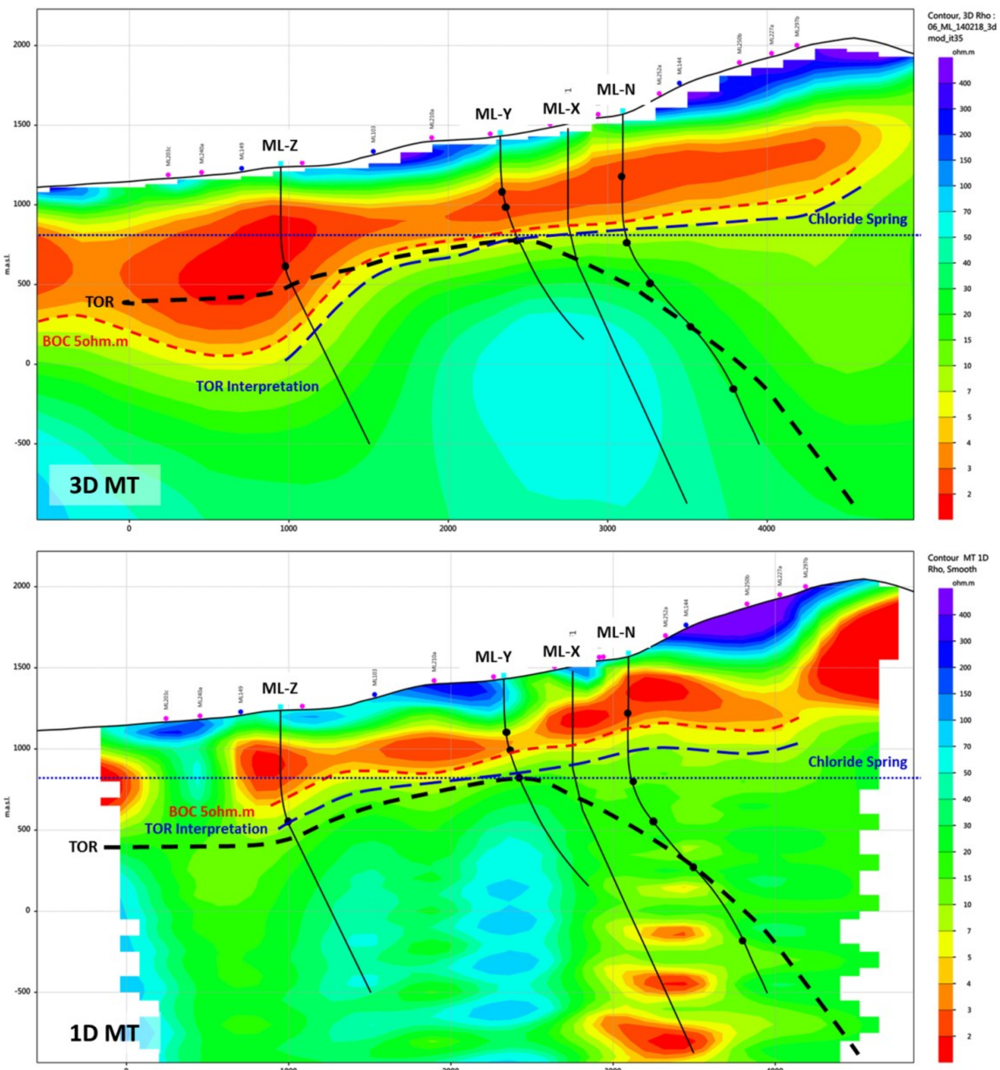

Figure 3: Muara Laboh 3D and 1D MT comparison. The 1D inversion tends to exaggerate changes near discontinuities and to displace them because of dimensional distortion, while 3D inversion will smooth the low resistivity and makes the layers extend to depths greater than is shown by the 1D inversion.

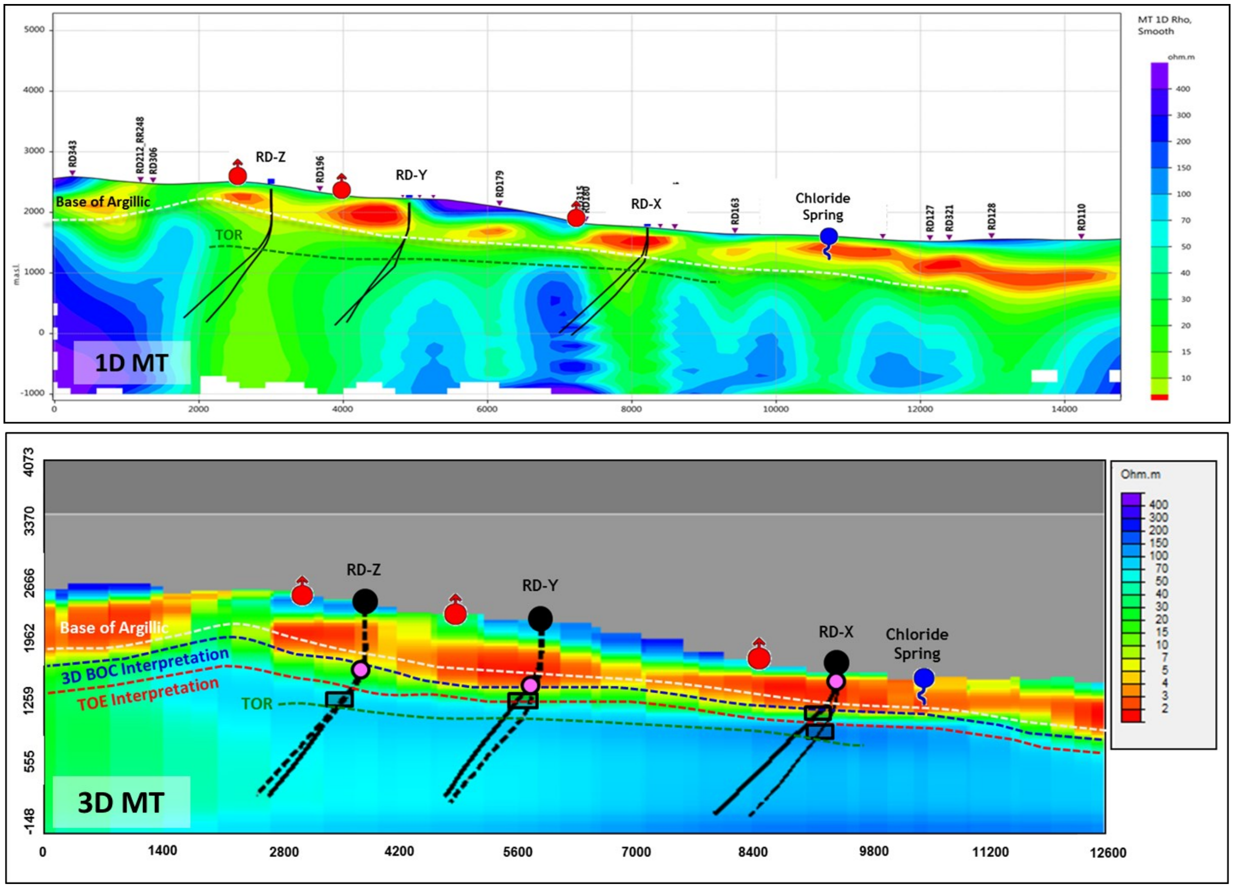

Figure 4: Rantau Dedap MT. Before drilling begin, the conductive layer in 1D-3D MT, the bottom of clay cap is represented by blue line/1D & 3D BOC Interpretation. BOC in 1D MT is shallower and tend to have discontinuity while BOC in 3D MT tends to be deeper and averaging the value. Value of >50 ohmmeters was interpreted as reservoir zone, represented by red line/TOW (Top of Epidote) Interpretation. During drilling, some revision has been made. White line = Base of Argilic are based on drilling data and laboratory analysis (XRD and petrography); green line = TOR based on wells completion test. Magenta dot represents first epidote appearance, black box represents continuous epidote, both based on drilling data.